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SIMULATION OF ARBITRARY SHAPED BOUNDARIES FOR HEMODYNAMIC STUDIES

Roger K. Debry, et al

Utah University

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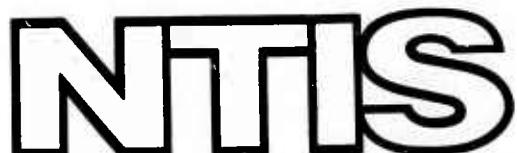
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Because such methods are typically large and cumbersome, the efficient implementation of this new technique was taken on as a concurrent investigation. The use of interactive computer graphics provides the user with the best approach to an efficient implementation, if it is applied in the right way.

Techniques for applying interactive computer graphics to the solution of hemodynamics problems involving flexible, arbitrarily shaped, no-slip boundaries are demonstrated for a particular problem. This problem involves the study of blood flow through a ball-type prosthetic heart valve. The results of this study agree closely with known experimental studies.

SIMULATION OF ARBITRARY SHAPED BOUNDARIES
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Roger K. Debry
Harvey Greenfield

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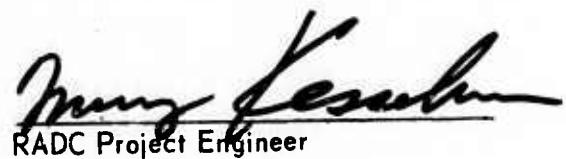
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PREFACE

Since the beginning of time, man has searched for answers to questions about himself and the world in which he lives. Out of this search have been born the many fields of science we know today. Most of these sciences had their beginnings with the ancient Babylonians, Egyptians, Phoenicians, and Greeks. By the 4th century B.C., Biology and Physics had begun, while Astronomy and Mathematics were well established sciences. Even applied sciences such as Medicine and Engineering had begun to emerge.

Often shrouded in mysticism, or dominated by religious and political thought, science seemed to advance or decline as a body. During periods of advancement in one field, similar gains are often found in others; progress in Astronomy and Biology, for example, was stimulated by the optical discoveries of the telescope and microscope. During the rise of Greek science, an interesting dichotomy appeared. Observation, which played a minor role in Astronomy and Physics, became prominent in Medicine. Hippocrates and Aristotle, the two Greeks of the period most interested in the life-sciences had little to do with Mathematics. Living things became exempt from mathematical treatment, and Medicine became the province of the non-mathematician [1]. Now, over 2000 years later, the medical scientist has found a very mathematical tool to aid him in his work - the digital computer.

Probably the first stored program electronic computer was the EDSAC developed at Cambridge University in 1949. Primarily designed to solve differential equations, early computers were strictly within

the realm of the mathematician. As computers became more powerful

and easier to use, their use became more general in other disciplines.

In 1956, the Air Research and Development Command of the U.S. Air

Force sponsored an investigation to explore the possible uses of the

computer in medical research [2].

In 1956, the National Aeronautics and Space Administration pub-

lished a report on the uses of the computer in the medical field. By

this time computers had been used in medical diagnosis, analog simul-

ation of physical systems, handling of medical records, and teaching [3].

Since the time of that report, the use of the computer in medicine has

been extended to include other administrative tasks, statistical

analysis, and patient monitoring [4].

The use of the computer to understand the physical phenomena of

the human body is still a relatively untouched field. There are

many systems within the human body that cannot be completely under-

stood using the physician's prime tool, observation. One of the most

important of these is the human circulatory system. Although a

great body of knowledge has been built up through the years, there are

still a great many unknowns about the way blood flows through the

body. Conventional means of measurement cannot answer these questions,

because the act of introducing a measurement device into the system

usually changes its characteristics.

By constructing a realistic mathematical model, the scientist

can use the digital computer to see into previously unknown worlds,

and find significant answers to problems regarding the circulatory

system. The mathematician, with the aid of the digital computer, has

a great deal to offer the field of medicine. It is hoped that the
kind of research represented here will be significant in bringing
together these two disciplines.

ABSTRACT

The research presented here is part of a continuing project at
the University of Utah, involved in the study of blood flow phenomena
in the human body. These studies involve the solution of a system of
non-linear, partial differential equations known as the Navier-Stokes
equations. Analytic solutions to these equations exist only for a
few special cases, therefore, numerical techniques have been developed
for approximating them. A particular requirement for hemodynamic
studies is that a solution technique exists which allows flexible,
arbitrarily shaped, no-slip boundaries to be defined in the model being
studied. The technique which is developed in this report allows
that kind of definition. It is a finite difference technique, based
on the Marker and Cell method developed at Los Alamos Scientific
Laboratory.

Because such methods are typically large and cumbersome, the
efficient implementation of this new technique was taken on as a
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provides the user with the best approach to an efficient implementa-
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shaped, no-slip boundaries are demonstrated for a particular problem. This problem involves the study of blood flow through a ball-type prosthetic heart valve. The results of this study agree closely with known experimental studies.

CHAPTER ONE

INTRODUCTION

The research reported on here is part of an on-going project at
the University of Utah, committed to the study of blood flow phenomena
in the human circulatory system [5]. Topics of current interest in
this area include the formation of atherosclerotic plaques, and the
problems associated with blood flow through artificial heart valves [6].
The numerical solution of this type of problem involves the solution
of a system of non-linear partial differential equations. This set of
equations, known as the Navier-Stokes equations is extremely difficult
to solve. Analytic solutions exist for only a few well known special
cases, where the proper assumptions reduce the equations to a solvable
form.

In recent years, numerical techniques have been developed which,
with the aid of the digital computer, can find solutions to a
broader class of fluid problems. Even these techniques however, take
advantage of special cases: straight walls, two-dimensional flow,
symmetry, etc. They are typically finite difference techniques,
and as such require large amounts of computer storage and large
execution times. As the problem becomes more and more complex, the
storage and run time requirements of the problem grow very, very fast.
For example, in a recent work reported on by Hirt and Cook [7], a
three-dimensional problem of limited resolution (15 computing cells
on a side) required 64,000 words of high speed store on a CDC-7600 com-
puter.

Although numerical techniques are becoming more powerful and more sophisticated, the trend seems to be for these techniques to rely heavily on the brute-force speed and large memory capacity of today's super-computers. They tend to neglect the more elegant features available on modern computing systems. It would seem that a certain level of sophistication would allow such problems to be run much more effectively. This does not mean that the goal here is to produce a faster piece of code, but rather one which is more efficient in its use of total machine resources. One way that this can be done is to give the user the capability to visually interact with his program.

Interactive computer graphics is certainly not a magic formula which will make a computation easier. In fact, if poorly designed, a programming system using interactive computer graphics may prove to be a serious handicap. Therefore, in suggesting the inclusion of an interactive graphics capability, the previously mentioned goal of program efficiency must be kept in mind.

The class of problems to be considered here involves the study of blood flow past artificial heart valves. In order that the problem be studied with as few simplifying assumptions as possible, a numerical technique of considerable power will be used. In addition, interactive computer graphics will be included as an integral part of the solution process. Considerable detail will be focused on keeping the entire program efficient in terms of the use of machine resources.

CHAPTER TWO

THE PHYSICAL PROBLEM

The heart is basically a four chambered pump. The major pump-
ing muscle of the heart is the left ventricle, which supplies oxygen-
ated blood to the entire body. The inflow valve to the left ventricle
is the mitral valve, and it's outflow valve is the aortic valve. It
is one of these two valves which is most often destroyed or impaired
genitically or by disease, even though two other valves exist in
the right side of the heart.

In the past few years, successful replacement of the natural
valve with an artificial one has brought about the development of
many different designs for artificial heart valves. Unfortunately, no
one valve completely fulfills all of the criteria for an ideal re-
placement to the natural valve [8]. By studying the flow character-
istics of currently available prosthetic heart valves, the results
could provide valuable insight into the design of a better valve.

The physical model chosen to study first was the Starr-Edwards
ball type valve. Because this is a very popular replacement for the
natural aortic valve, some detailed study of its flow characteristics
seems to be in order. The environment for this model is the heart
valve test chamber developed by Weiting at the University of Texas [9].
This provides experimental results for later comparison and evaluation
for the chamber was carefully designed, according to data derived
from cadaver heart measurements.

The valve testing chamber shown in Figure 1 was designed by

Wieting such that the cross-sectional flow areas were analogous to those in the human heart.
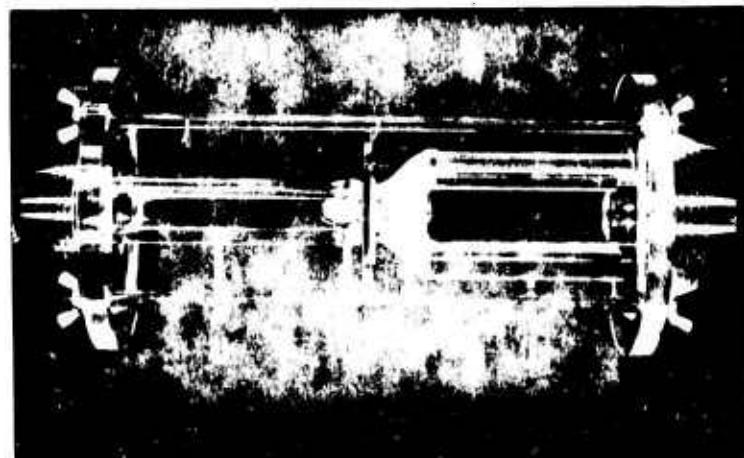
Figure 1
Wieting Heart Valve Rest Chamber

A cross-sectional view of the chamber is shown in Figure 2. In this drawing, a ball type valve such as the one to be studied is shown in the open position.
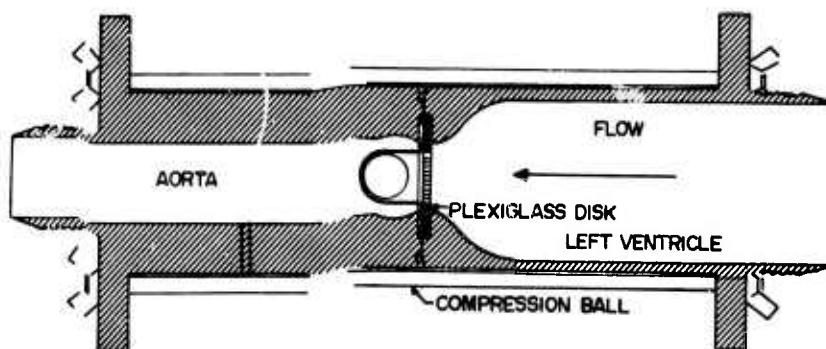
Figure 2
Cross Section of Chamber

Placing this cross section in an r-z reference frame, as shown in

Figure 3, the coordinates of points along the wall of the chamber

can be determined. These points then provide a description of the

boundaries for the computer program. This list of points is contained

in Table I.
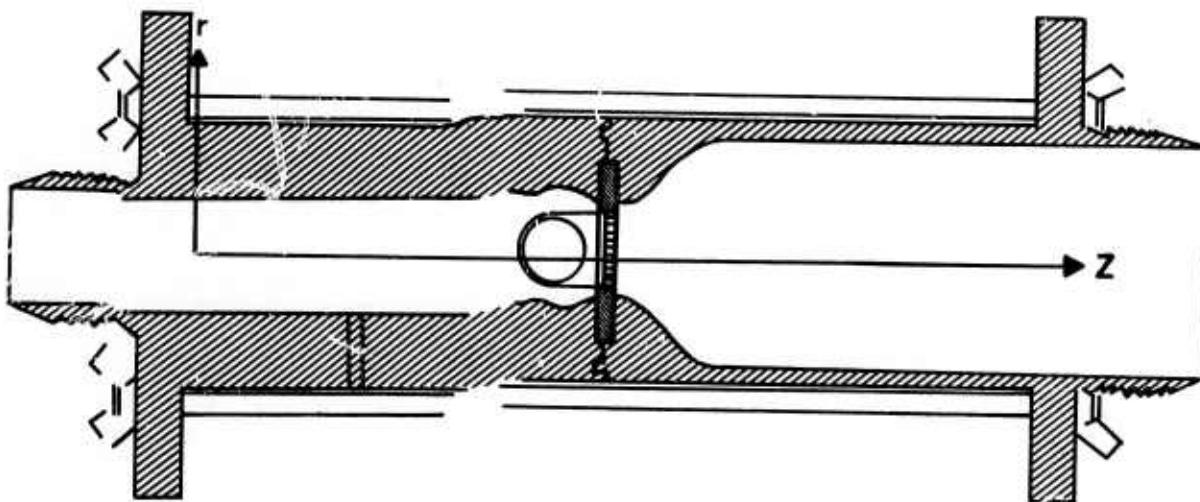
Figure 3

Coordinate Axes Used to Obtain Computer
Input for Test Chamber Description

TABLE I

INPUT POINTS FOR BOUNDARY DESCRIPTION

COORDINATES IN MM

R	Z
0	0
1.7	0
1.7	6.8
1.58	7.31
1.56	7.56
1.58	7.82
1.62	8.07
1.736	8.53
1.736	8.78
1.683	9.04
1.524	9.42
0.89	9.48
0.846	9.74
0.90	9.99
1.397	10.10
1.46	10.35
1.65	10.73
2.984	12.13
3.175	12.51
3.2	12.89

TABLE I

Continued

R	Z
3.2	16.0
0	16.0
0	9.255
0.198	9.233
0.388	9.171
0.561	9.072
0.700	8.938
0.827	8.777
0.908	8.595
0.949	8.399
0.949	8.209
0.908	8.105
0.827	7.823
0.700	7.662
0.561	7.528
0.388	7.429
0.198	7.367
0	7.345
0	0

CHAPTER THREE

THE DEVELOPMENT OF THE MATHEMATICAL MODEL

A. THE EQUATIONS OF FLUID FLOW

The mathematical study of fluid dynamics is based upon the principles of conservation of mass, momentum and energy. These principles can be expressed in the form of partial differential equations. Derivation of these equations are found in standard fluid dynamics texts such as those by Lightfoot [10] or Batchelor [11]. For simple two-dimensional flow they are:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \tag{1}$$

$$\rho \left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} \right) + \frac{\partial p}{\partial x} = 0, \tag{2}$$

$$\rho \left(\frac{\partial u}{\partial t} + \frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} \right) + \frac{\partial p}{\partial y} = 0. \tag{3}$$

Equation (1) is the continuity equation, and equations (2) and (3) are the Navier-Stokes equations for two-dimensional incompressible flow. In these equations, u and v are velocities in the x and y directions respectively, ρ is the density of the fluid, and p the pressure in the fluid.

Since blood is a viscous fluid, in our particular study involving incompressible flow, we must consider the effects of viscosity. This results in the set of equations:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \tag{4}$$

$$\rho \left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} \right) + \frac{\partial p}{\partial x} = -\mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right), \tag{5}$$

$$\rho \left(\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} \right) + \frac{\partial p}{\partial y} - \mu \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right), \tag{6}$$

where μ is the viscosity of the fluid.

Dividing equations (5) and (6) through by ρ, we get:

$$\frac{\partial u}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + \frac{\partial \emptyset}{\partial x} = -\nu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right), \tag{7}$$

$$\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + \frac{\partial \emptyset}{\partial y} = -\nu \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right). \tag{8}$$

Here $\nu = \mu/\rho$, the kinematic viscosity of the fluid, and $\emptyset = p/\rho$.

In the more familiar vector form these equations are:

$$\nabla \cdot \vec{u} = 0 \tag{9}$$

$$\frac{\partial \vec{u}}{\partial t} = (\vec{u} \cdot \nabla)\, \vec{u} - \nabla\emptyset + \nu\nabla^2\vec{u}. \tag{10}$$

The motion of the fluid is described in equation (10) in terms of:

1. $(\vec{u} \cdot \nabla)\vec{u}$ The convection of momentum by fluid motion.

2. $-\nabla\emptyset$ The momentum change due to pressure forces.

3. $\nu\nabla^2\vec{u}$ The diffusion of momentum by viscous forces.

Equations of this kind cannot be solved analytically. However, approximation methods have been devised which, with the aid of the modern computer, can realize extremely good solutions to fluid problems. One class of such methods is that of finite differences. The use of such techniques is discussed at length in Forsythe and Wasow [12], and Varga [13]. The techniques used by the present investigator are of this class.

B. FINITE DIFFERENCE TECHNIQUES

Fundamental to most numerical techniques for the solution of partial differential equations is the fact that the derivatives of a function can be expressed in terms of values of the function or differences in values of the function at different points in the region over which the function is defined. Given an arbitrary function $U = U(X)$, and assuming that U possesses a sufficient number of derivatives, the value of U at two points X and $X + h$ can be related by the Taylor's series expansion

$$U (X + h) = U (X) + U' (X) h + \ldots$$

$$\ldots + \frac{U^{(n-1)}(X)}{(n-1)!} h^{n-1} + \frac{h^n}{n!} U^{(n)} (X_1) \tag{11}$$

where X_1 lies between X and X+h. As h, the incremental distance between these two arbitrary points, is allowed to become very small, the high order terms of the expansion approach zero, and can be

lumped together as an error term. Now expand U_{i+1} and U_{i-1} in a Taylor series expansion about the central point U_i.
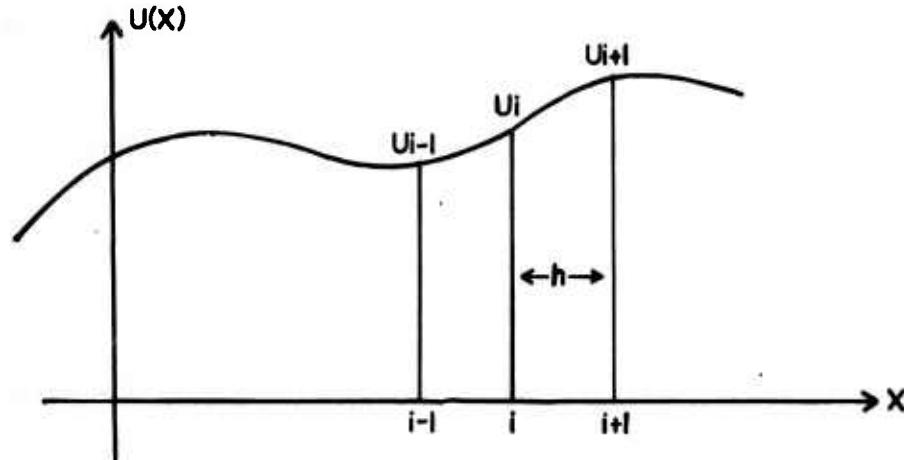
Figure 4

Using a Taylor's Series to Approximate
the Function U = U(x)

This results in the two equations:

$$U_{i-1} = U_i - h \frac{du}{dx} + h^2 \frac{d^2u}{dx^2} - h^3 \frac{d^3u}{dx^3} + 0 \ [\ h^4] \qquad (12)$$

and

$$U_{i+1} = U_i + h \frac{du}{dx} + h^2 \frac{d^2u}{dx^2} + h^3 \frac{d^3u}{dx^3} + 0 \ [\ h^4], \qquad (13)$$

where all derivatives are evaluated at the point X = i. Subtracting equation (13) from equation (12) gives the three point, central finite difference formula for the first order derivative of U at X = i as

$$\frac{du}{dx} = \frac{U_{i+1} - U_{i-1}}{2h} + 0 \ [\ h^2 \ ]. \qquad (14)$$

Similar derivations give the forward difference formula

$$\frac{du}{dx} = \frac{U_{i+1} - U_i}{h} + 0[h],$$ (15)

and the backward difference formula

$$\frac{du}{dx} = \frac{U_i - U_{i-1}}{h} + 0[h].$$ (16)

The usefulness of these difference formulae can be demonstrated by considering a simple differential equation:

$$\frac{dz}{dx} = F(x,z) \quad , \quad z(x_0) = z_0.$$ (17)

The derivative $\frac{dz}{dx}$ at the point x_0 can be approximated using the forward difference formula of equation (15) as:

$$\frac{dz}{dx}\bigg|_{x=0} \approx \frac{z_1 - z_0}{h}$$ (18)

Applying this approximation to the given differential equation (17)

$$z(x_1) = z(x_0) + hF(x_0, y_0)$$ (19)

gives an approximation to the solution of equation (17) at the point x_1.

Clearly, successive applications of this difference scheme will result in solutions to the equation for all values of x for which the function is defined.

Extending this derivation to functions of two variables also results in the central difference forms useful in the solution of partial difference equations:

$$\frac{\partial u}{\partial x} = \frac{U_{i+1,j} - U_{i-1,j}}{2h} + 0 \: [\: h^2 \:], \tag{20}$$

$$\frac{\partial^2 u}{\partial x^2} = \frac{U_{i-1,j} - 2U_{i,j} + U_{i+1,j}}{h^2} + 0[\: h^2 \:], \tag{21}$$

Similar forms exist for $\frac{\partial u}{\partial y}$, $\frac{\partial^2 u}{\partial y^2}$, and $\frac{\partial^2 u}{\partial x \partial y}$.

An equation which frequently appears in studies of fluid dynamics is Poisson's equation

$$\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2} = g \: (x,y). \tag{22}$$

Consider solving this equation over some region R with some appropriate boundary conditions along the boundary B. By superimposing a square mesh on the region R, as in Figure 5 , the finite difference forms of the derivatives at the point (X_1, Y_1) can be written
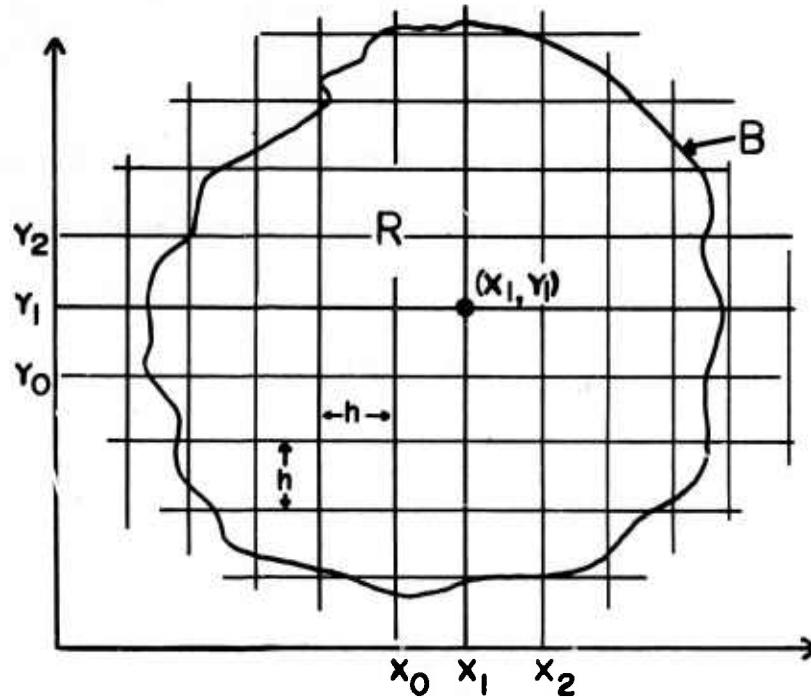
Figure 5

The Use of a Mesh in Deriving Finite Difference Equations

$$\frac{\partial^2 U}{\partial x^2} = \frac{U(X_0, Y_1) - 2U(X_1, Y_1) + U(X_2, Y_1)}{h^2} \tag{23}$$

and

$$\frac{\partial^2 U}{\partial y^2} = \frac{U(X_1, Y_0) - 2U(X_1, Y_1) + U(X_1, Y_2)}{h^2} \tag{24}$$

Using these approximations, equation (22) can be written as

$$\frac{U(X_o,Y_1) + U(X_2,Y_1) + U(X_1,Y_o) + U(X_1Y_2) - 4U(X_1,Y_1)}{h^2} \quad (25)$$

$$= g(X_1,Y_1).$$

An analogous equation may be written for every point interior to B, being careful to use the appropriate boundary conditions for points near B. This leads to a system of linear equations in the unknowns $U(X_i,Y_i)$ which can be solved for by some iterative technique. All of the methods discussed in this paper are based on this use of finice difference equations.

C. STREAM FUNCTION AND VORTICITY

In general, solutions to problems in fluid dynamics are difficult to obtain. The most popular technique for simplifying the equations has been the introduction of stream function and vorticity as primary variables.

In considering the flow of an incompressible fluid, the mass conservation equation

$$\frac{\partial p}{\partial t} + \nabla \cdot (\rho \vec{U}) = 0 \quad (26)$$

reduces to the statement that a vector divergence is zero. If the flow field is two-dimensional, this vector divergence is the sum of only two derivatives. From the mass conservation equation given previously in equation (1) it follows that udy-vdx is an exact differential,

say equal to $d\psi$. Then

$$u = \frac{\partial \psi}{\partial y} , \quad v = - \frac{\partial \psi}{\partial x} \tag{27}$$

In this way we have used the mass-conservation equation to replace the two dependent variables u,v by the single dependent variable ψ, which is a very valuable simplification in many cases of two-dimensional flow.
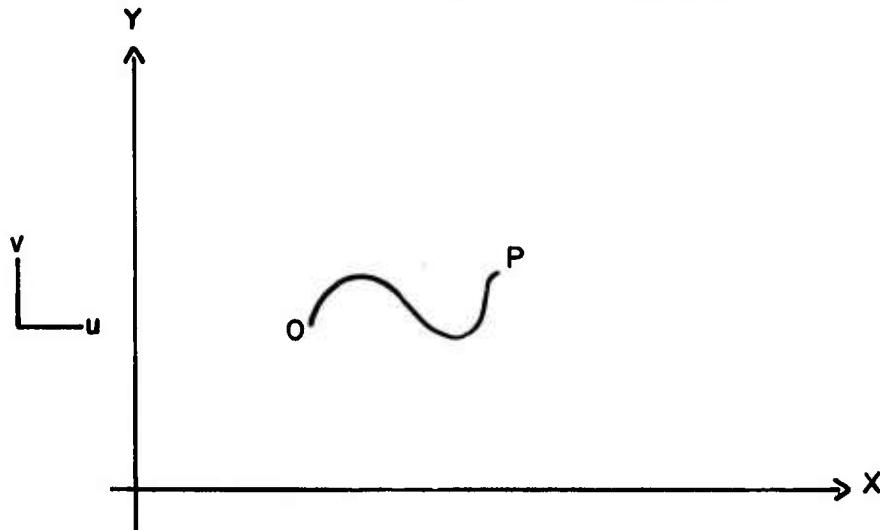
Figure 6

Derivation of Stream Function

The scalar function ψ is now defined by

$$\psi - \psi_0 = \int (udy - vdx), \tag{28}$$

where ψ_0 is a constant and the line integral is taken along an arbitrary curve joining some reference point 0 to the point P with coordinates x,y, as shown in Figure (6). From this we can show that the flux of volume across the closed curve formed from any two paths joining 0 and P is necessarily zero when the enclosed region is wholly occupied

by incompressible flow. The flux then is independent of the path, and defines a function of the position of P. Since the flux of volume across any curve joining two points is equal to the difference between the values of ψ at these two points, it follows that ψ is constant along a streamline. ψ is therefore termed the stream function.

Another important concept in simplifying the equations is vorticity. The vorticity, or rotation, of a fluid is given by

$$\vec{\omega} = \nabla \times \vec{u} \tag{29}$$

Again, restricting analysis to two-dimensional flow, there exists only one component of vorticity, namely

$$\omega z = \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y} . \tag{30}$$

Almost all of the solution techniques that this author is acquainted with use stream function and vorticity to simplify the equations of fluid flow. A few of these techniques are outlined below.

D. SOME PREVIOUSLY USED NUMERICAL TECHNIQUES

One of the earliest attempts to solve numerically a problem of time dependent two-dimensional incompressible viscous flow was done by Fromm [14] at Los Alamos. Fromm's use of stream function and vorticity is representative of most numerical techniques.

Taking the curl of equation (10), and using the definition

of vorticity of equation (29), results in the vorticity transport
equation

$$\frac{\partial \omega}{\partial t} = \nabla^2 \omega + \frac{\partial \omega}{\partial y} \frac{\partial \psi}{\partial x} - \frac{\partial \omega}{\partial x} \frac{\partial \psi}{\partial y} . \qquad (31)$$

The definition of vorticity (29) can be written in terms of stream
function

$$\omega = -\frac{1}{2} \nabla \psi . \qquad (32)$$

This equation is a Poisson's equation, and can be solved by some itera-
tive technique, using finite differences as outlined previously.

Fromm begins with some initial guess for his solution. Time is
then advanced, and a finite difference form of equation (31) is used to
compute new vorticities thoughout the mesh. Using the updated vorti-
cites, equation (32) is solved for the ψ field. An improved Liebmann's
method was used [15], taking advantage of any available advanced values
of neighboring points. The iteration continues until the field settles
down. Finally, new velocity components corresponding to the updated ψ
values are calculated, and then used to obtain corrected vorticity
values at walls and obstacles. This process is then repeated until some
appropriate convergence criterion is satisfied.

Fromm's method suffered from a poor approximation of the boundary
conditions, and the requirement for stability and accuracy of excess-
ively small time steps. Steps to improve the application of the boun-
dary conditions and the iterative procedures were taken by Pearson [16],

and Esch [17]. Stream function-vorticity methods still have several
difficulties. First, the boundary conditions are difficult to apply,
especially to a free surface. Second, extension to three-dimensions
and cylindrical coordinates involves a great effort. These difficul-
ties have been overcome by solving the Navier-Stokes equations in terms
of the primary variables velocity and pressure. This work was done by
Harlow et al. [18] at Los Alamos.

CHAPTER FOUR

THE DEVELOPMENT OF THE NUMERICAL METHOD

A. THE MARKER AND CELL TECHNIQUE

Developed at Los Alamos, the Marker and Cell [19] (MAC) technique for computing time-dependent, viscous, incompressible fluid flows in several space dimensions, was the first such method to use the primary variables velocity and pressure. The MAC technique utilizes the full Navier-Stokes equations, without the usual simplifying assumptions. The MAC methodology as described here forms the basis for later developments which were used in this research.

The Solution Technique

The MAC method uses two coordinate systems. The primary coordinate system covers the region of interest with a rectangular mesh, each cell of dimension δx by δy. If the cells are numbered by indices I and J, such that I counts the columns in the X direction and J the rows in the Y direction, then the field variables describing the flow field can be positioned as shown in Figure 7 .
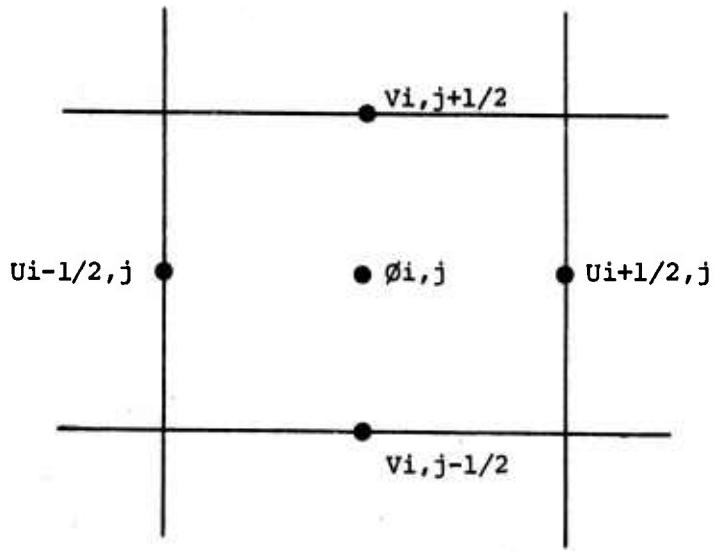
Figure 7

Location of Primary Variables in MAC Finite Difference Grid

The variables are placed as shown in order to maintain conservation. If the field variables are placed at the cell centers, the finite difference equation for pressure would require the involvement of the next layer of cells beyond that which immediately surrounds any central cell in order to attain rigorous finite-difference mass conservation. This means that the solution technique becomes much more complex, in addition to the inaccuracies introduced by using far-distant quantities.

Besides the coordinate system attached to the finite difference cells, there is a coordinate system of particles whose motions describe the trajectories of fluid elements. The marker particles serve two functions: first they show which cells are free surface cells. Second,

they show the motion of the fluid as it passes through the computing region.

The calculation is carried out by advancing the entire fluid configuration through a small, but finite, time increment. The results of each time cycle acts as the initial conditions for the next one, and the computation continues as long as the fluid motion is of interest. The steps in each cycle are outlined below:

1) The pressure for each cell is obtained by solving a finite-difference Poisson's equation, whose source term is a function of the velocities. This equation was derived subject to the requirement that the resulting momentum equations should produce a new velocity field that satisfies the incompressibility condition.

2) The full finite-difference Navier-Stokes equations are used to find the new velocities throughout the mesh.

3) The marker particles are moved to their new positions, using for their velocities simple interpolated values from the nearby cells.

4) Bookkeeping processes are accomplished related to the creation or destruction of surface cells, the input or output of particles, the advancement of a time counter, printing or plotting results, and numerous similar matters.

The Finite Difference Equations

Returning to the Navier-Stokes equations, the finite difference form of equation (9) can be written for MAC usage as

$$D_{ij} \equiv \frac{1}{\theta x} \left(u_{i+1/2,j} - u_{i-1/2,j}\right) + \frac{1}{\delta y} \left(v_{i,j+1/2} - v_{i,j-1/2}\right) \quad (33)$$

The incompressibility condition then becomes

$$D_{ij} \equiv 0 \quad (34)$$

which is required at every cell, at every time step. Rewriting equation (10) as

$$\frac{\partial \vec{u}}{\partial t} = -\nabla \cdot (\vec{u}\vec{u}) - \nabla \phi + \nu \nabla^2 \vec{u}, \quad (35)$$

The finite difference equations can be written

$$\frac{1}{\delta t} \left(u_{i+1/2,j}^{n+1} - u_{i+1/2,j}\right) = - \frac{1}{\delta x}\left[(u_{i,j})^2 - (u_{i+1,j})^2\right]$$

$$- \frac{1}{\delta y}\left[(uv)_{i+1/2,j-1/2} - (uv)_{i+1/2,j+1/2}\right]$$

$$+ g_x - \frac{1}{\delta x}\left(\phi_{i,j} - \phi_{i+1,j}\right)$$

$$+ \nu \left[\frac{1}{\delta x^2}\left(u_{i+3/2,j} + u_{i-1/2,j} - 2u_{i+1/2,j}\right.\right.$$

$$\left.\left. + \frac{1}{\delta y^2}\left(u_{i+1/2,j+1} + u_{i+1/2,j-1} - 2u_{i+1/2,j}\right)\right]\right.$$

$$(36)$$

and

$$\frac{1}{\delta t} \left(v_{i,j+1/2}^{n+1} - v_{i,j+1/2} \right) = \frac{1}{\delta x} \left[(uv)_{i-1/2,j+1/2} - (uv)_{i+1/2,j+1/2} \right]$$

$$+ \frac{1}{\delta y} \left[(v_{i,j})^2 - (v_{i,j+1})^2 \right]$$

$$+ g_y + \frac{1}{\delta y} \left(\phi_{i,j} - \phi_{i,j+1} \right)$$

$$+ \nu \left[\frac{1}{\delta x^2} (v_{i+1,j+1/2} + v_{i-1,j+1/2} - 2v_{i,j+1/2}) \right.$$

$$\left. + \frac{1}{\delta y^2} (v_{i,j+3/2} + v_{i,j-1/2} - 2v_{i,j+1/2}) \right] ,$$

$$(37)$$

where g_x and g_y are the gravity components. Equations (36) and (37) are immediately available for computing new velocities, and in fact are the equations used in step (2) of the computing technique outlined previously.

Now it is only necessary to find an equation for the pressures. In order to do this, first define

$$Q_{ij} \equiv \frac{1}{\delta x^2} \left[(u_{i+1,j})^2 + (u_{i-1,j})^2 - 2(u_{i,j})^2 \right]$$

$$+ \frac{1}{\delta y^2} \left[(v_{i,j+1})^2 + (v_{i,j-1})^2 - 2(v_{i,j})^2 \right]$$

$$+ \frac{2}{\delta x \delta y} \left[(uv)_{i+1/2,j+1/2} + (uv)_{i-1/2,j-1/2} - (uv)_{i+1/2,j-1/2} \right.$$

$$\left. - (uv)_{i-1/2,j+1/2} \right] .$$

$$(38)$$

From equations (36) and (37) it follows that

$$\frac{1}{\delta t}\left(D_{i,j}^{n+1} - D_{i,j}\right) = -Q_{i,j} - \frac{1}{2}(\phi_{i+1,j} + \phi_{i-1,j} - 2\phi_{i,j})$$

$$- \frac{1}{\delta y^2}(\phi_{i,j+1} + \phi_{i,j-1} - 2\phi_{i,j})$$

$$+ \nu\left[\frac{1}{\delta x^2}(D_{i+1,j} + D_{i-1,j} - 2D_{i,j}) + \frac{1}{\delta y^2}(D_{i,j+1} + D_{i,j-1} - 2D_{i,j})\right]. \quad (39)$$

By setting $D_{i,j}^{n+1} = 0$ in this equation, the fundamental equation for finding the pressures is

$$\frac{1}{\delta x^2}(\phi_{i+1,j} + \phi_{i-1,j} - 2\phi_{i,j}) + \frac{1}{\delta y^2}(\phi_{i,j+1} + \phi_{i,j-1} - 2\phi_{i,j}) = -R_{i,j} \quad (40)$$

where

$$R_{i,j} \equiv Q_{i,j} - \frac{D_{i,j}}{\delta t}$$

$$-\nu\left[\frac{1}{\delta x^2}(D_{i+1,j} + D_{i-1,j} - 2D_{i,j}) + \frac{1}{\delta y^2}(D_{i,j+1} + D_{i,j-1} - 2D_{i,j})\right] \quad (41)$$

Equation (40) is a Poisson's equation, and must be satisfied by some iterative method.

Boundary Conditions

Rigid walls, inflow boundaries, and outflow boundaries are confined to follow cell boundaries. This means that all side or obstacle walls must be horizontal or vertical.

If the wall is to allow for Free-slip (i.e. there is no friction between the wall and the fluid), then whenever an equation calls for use of an exterior tangential velocity, the calculation simply uses the value of the tangential velocity at the image point back in the computing region. If an exterior normal velocity is required, the negative of the image value is used so that the normal component of the velocity in fact vanishes at the wall.

If the wall is no-slip (i.e. the tangential component of the fluid velocity = 0 along the wall), then the exterior tangential component must be the negative of the image point. In order that D_{ij} vanish for exterior cells, this requires the external normal velocity components to have the same value as they do at their image interior points.

Expressions relating the normal difference of the pressure to the normal component of the body force and the viscous diffusion of normal momentum are contained in the momentum equations. These expressions supply the needed boundary information for solution of the $\emptyset$-equation.

B. SIMPLIFIED MARKER AND CELL TECHNIQUE

It is the application of these boundary conditions in the $\emptyset$-equation which makes the MAC method unduly complicated. In addition, the solution of the Poisson's Equation is very difficult, and does not lend itself well to fast solution techniques. In order to overcome these difficulties, the Los Alamos Group modified the Marker and Cell method, making it much simpler to work with.

The procedure for each computational cycle as outlined by Amsden

and Harlow [20] is outlined below:

    1. A tentative field of advanced-time velocities is calculated by using an arbitrary pressure field within the fluid, but with a pressure boundary condition at the free surface satisfying the normal stress condition. Correct velocity boundary conditions assure that this tentative velocity field contains the correct vorticity at every interior point in the fluid. The tentative velocities do not, however, have $\nabla \cdot \vec{u} = 0$.

    2. The tentative velocities are modified to their final values so as to preserve the vorticity at every point. A potential function is employed, determined by the requirement that it convert the velocity field to one which satisfies the incompressibility condition everywhere.

To begin, the basic equations (7), (8), and (1) are rewritten to make use of cylindrical coordinates:

$$\frac{\partial u}{\partial t} + \frac{1}{r^\alpha} \frac{\partial r^\alpha u^2}{\mu \partial r} + \frac{\partial uv}{\partial z} = -\frac{\partial \phi}{\partial r} + g_r + \nu \frac{\partial}{\partial z}\left(\frac{\partial u}{\partial z} - \frac{\partial v}{\partial r}\right), \qquad (42)$$

$$\frac{\partial v}{\partial t} + \frac{1}{r^\alpha} \frac{\partial r^\alpha uv}{\partial r} + \frac{\partial v^2}{\partial z} = -\frac{\partial \phi}{\partial z} + g_z - \frac{\nu}{r^\alpha} \frac{\partial}{\partial r}\left[r^\alpha\left(\frac{\partial u}{\partial z} - \frac{\partial v}{\partial r}\right)\right], \quad (43)$$

and

$$D \equiv \frac{1}{r^\alpha} \frac{\partial r^\alpha u}{\partial r} + \frac{\partial v}{\partial z} = 0 \ . \qquad (44)$$

The velocity components, u and v, are respectively in the r and z directions, and the pressure, ϕ, is normalized to unit density. Plane cartesian coordinates have $\alpha=0$, and cylindered corrdinates have $\alpha= 1$.

Writing the finite difference forms of these quations, specifying the advance time velocities with a tilde:

$$\frac{\tilde{u}^{n+1}_{i+1/2,j} - u^n_{i+1/2,j}}{\delta t} =$$

$$\frac{r^{\alpha}_i u^n_{i+i/2,j}\ u^n_{i-1/2,j} - r^{\alpha}_{i+1}\ u^n_{i+3/2,j}\ u^n_{i+1/2,j}}{r^{\alpha}_{i+1/2} \delta r}$$

$$+ \frac{u^n_{i+1/2,j-1/2}\ v^n_{i+1/2,j-1/2} - u^n_{i+1/2,j+1/2}\ v^n_{i+1/2,j+1/2}}{\delta z}$$

$$+ \frac{\theta_{i,j} - \theta_{i+1,j}}{\delta r} + g_r$$

$$+ \nu\left[\frac{1}{\delta z^2}\ (u^n_{i+1/2,j+1} + u^n_{i+1/2,j-1} - 2u^n_{i+1/2,j})\right.$$

$$\left. - \frac{1}{\delta r \delta z}\ (v^n_{i+1,j+1/2} - v^n_{i+1,j-1/2} - v^n_{i,j+1/2} + v^n_{i,j-1/2})\right]$$

$$(45)$$

$$\frac{\tilde{v}^{n+1}_{i,j+1/2} - v^{n}_{i,j+1/2}}{\delta t} =$$

$$\frac{r^{\alpha}_{i-1/2}\, u^{n}_{i-1/2,j+1/2}\, v^{n}_{i-1/2,j+1/2} - r^{\alpha}_{i+1/2}\, u^{n}_{i+1/2,j+1/2}\, v^{n}_{i+1/2,j+1/2}}{r^{\alpha}_{i}\delta r}$$

$$+ \frac{v^{n}_{i,j+1/2}\, v^{n}_{i,j-1/2} - v^{n}_{i,j+3/2}\, v^{n}_{i,j+1/2}}{\delta z}$$

$$+ \frac{\theta_{i,j} - \theta_{i,j+1}}{\delta z} + g_{z}$$

$$- \frac{\nu}{r^{\alpha}_{i}\delta r}\left[r^{\alpha}_{i+1/2}\ \left(\frac{u^{n}_{i+1/2,j+1} - u^{n}_{i+1/2,j}}{\delta z} \right.\right.$$

$$- \left. \frac{v^{n}_{i+1,j+1/2} - v^{n}_{i,j+1/2}}{\delta r} \right)$$

$$- r^{\alpha}_{i-1/2}\ \left(\frac{u^{n}_{i-1/2,j+1} - u^{n}_{i-1/2,j}}{\delta z} - \frac{v^{n}_{i,j+1/2} - v^{n}_{i-1,j+1/2}}{\delta r} \right)\Bigg] , \qquad (46)$$

and

$$D^{n+1}_{i,j} \equiv \frac{r^{\alpha}_{i+1/2}\, u^{n+1}_{i+1/2,j} - r^{\alpha}_{i-1/2}\, u^{n+1}_{i-1/2,j}}{r^{\alpha}_{i}\delta r}$$

$$+ \frac{v^{n+1}_{i,j+1/2} - v^{n+1}_{i,j-1/2}}{\delta z} = 0 . \qquad (47)$$

The finite difference approximation can now be written for the vorticity as:

$$\omega^{n}_{i+1/2,j+1/2} \equiv \frac{u^{n}_{i+1/2,j+1} - u^{n}_{i+1/2,j}}{\delta z}$$

$$- \frac{v^{n}_{i+1,j+1/2} - v^{n}_{i,j+1/2}}{\delta r} . \qquad (48)$$

Equations (45) and (46) can be combined to give a vorticity transport equation. This equation can be shown to be independent of the pressure field, θ. This means that any field of pressure inserted into the Navier Stokes equations will assure that the resulting velocity field carries the correct vorticity. This velocity field, however, does not satisfy the condition that $D_{i,j}$ vanish for each cell. It is necessary then to convert the tilde velocities into a final velocity field so that $D_{i,j} = 0$ for every cell. This must be done so that the vorticity already determined is preserved. This implies that the change in velocity be given by a gradient of a potential function, which will be called β. This can be written

$$U_{i+1/2,j}^{n+1} = \tilde{U}_{i+1/2,j}^{n+1} - \frac{1}{\delta r} (\beta_{i+1,j} - \beta_{i,j}) , \tag{49}$$

$$V_{i,j+1/2}^{n+1} = \tilde{V}_{i,j+1/2}^{n+1} - \frac{1}{\delta z} (\beta_{i,j+1} - \beta_{i,j}) , \tag{50}$$

Now, with equation (47) and equations (49) and (50), it follows that

$$D_{i,j}^{n+1} = \tilde{D}_{i,j} - \frac{1}{r_i^\alpha \delta r^2} \left[r_{i+1/2}^\alpha (\beta_{i+1,j} - \beta_{i,j}) \right.$$
$$\left. - r_{i-1/2}^\alpha (\beta_{i,j} - \beta_{i-1,j}) \right]$$
$$- \frac{1}{\delta_z^2} (\beta_{i,j+1} + \beta_{i,j-1} - 2\beta_{i,j}) . \tag{51}$$

Since it is required that $D_{i,j}^{n+1} \equiv 0$ for every cell, the value of $\beta_{i,j}$ for every cell can be expressed as

$$\beta_{i,j}^{h+1} = \frac{(1 + \alpha)}{(\frac{2}{\delta_r^2} + \frac{2}{\delta_z^2})}$$

$$\left[- D_{i,j} + \frac{r_{i+1/2} \beta_{i+1,j}^h + r_{-1/2} \beta_{i-1,j}^{h+1}}{- r_i \delta r^2} \right.$$

$$\left. + \frac{\beta_{i,j+1}^h + \beta_{i,j-1}^{h+1}}{\delta_z^2} \right] - \alpha \beta_{i,j}^h. \tag{52}$$

Here, h indicates the iteration number, and α an over-relaxation parameter. The iteration sequence proceeds until appropriate convergence criteria are satisfied.

C.   ARBITRARY BOUNDARY MARKER AND CELL TECHNIQUE

The restriction placed on most finite difference schemes, that the boundaries of theproblem must lie on the computational mesh, is most severe. In effect, this means that one must restrict his problem to having rectangular walls. In the particular application of the heart valve, it is certainly desirable to have boundaries of any arbitrary shape.

Mr. J.A. Viecelli developed a generalization of the Marker and Cell Technique at the Lawrence Radiation Laboratory [21]. Known as the Arbitrary Boundary Marker and Cell Technique (ABMAC) it treats the fluid boundary at an arbitrarily curved wall or obstacle as a free surface, to which a pressure is applied such taht the particles at the boundary move tangent to it. In order to calculate the pressure along the free surface, the usual MAC iteration formula is replaced by a simultaneous scheme proposed by Chorin [22,23].

Using centered differences in a cylindrical coordinate system, equation (7) can be written

$$u_{i+1/2,j}^{n+1} = u_{i+1/2,j} - \frac{\Delta t}{r^{\alpha}\Delta r}\left[(r^{\alpha}u^2)_{i+1j}^{n} - (r^{\alpha}u^2)_{ij}^{n}\right] - \frac{\Delta t}{\rho\Delta r}\left[P_{i+1j} - P_{ij}\right]$$

$$- \frac{\Delta t}{\Delta z}\left[(vu)_{i+1/2,j+1/2}^{n} - (vu)_{i+1/2,j-1/2}^{n}\right] - g_r\Delta t$$

$$+ \frac{\nu\Delta t}{\Delta z^2}\left[u_{i+1/2,j+1}^{n} - 2u_{i+1/2,j}^{n} + u_{i+1/2,j-1}^{n}\right]$$

$$- \nu\frac{\Delta t}{\Delta r\Delta z}\left[v_{i+1,j+1/2}^{n} - v_{i+1,j-1/2}^{n} - v_{i,j+1/2}^{n} + v_{i,j-1/2}^{n}\right]$$

$$(53)$$

By combining the old velocity, advection, body force, and viscous terms, and calling the resultant $\eta_{i+1/2j}^{n}$, equation (53) becomes

$$u_{i+1/2,j}^{n+1} = \eta_{i+1/2,j}^{n} - \frac{\Delta t}{\rho\Delta r}\left[P_{i+1j} - P_{ij}\right] . \qquad (54)$$

Similarily the finite difference form of equation (8)

$$v_{i,j+1/2}^{n+1} = v_{i,j+1/2}^{n} - \frac{\Delta t}{\Delta z}\left[(v^2)_{i,j+1}^{n} - (v^2)_{ij}^{n}\right] - \frac{\Delta}{\rho\Delta z}\left[P_{ij+1} - P_{ij}\right]$$

$$- \frac{\Delta t}{r^{\alpha}\Delta r}\left[(r^{\alpha}uv)_{i+1/2,j+1/2}^{n} - (r^{\alpha}uv)_{i-1/2,j+1/2}^{n}\right] - g_z\Delta t$$

$$- \frac{\nu\Delta t}{r^{\alpha}\Delta r\Delta z}\left[\left(u_{i+1/2,j+1}^{n} - u_{i+1/2,j}^{n}\right)r_{i+1/2}^{\alpha} - \left(u_{i-1/2,j+1}^{n} - u_{i-1/2,j}^{n}\right)r_{i-1/2}^{\alpha}\right]$$

$$- \frac{\nu\Delta t}{r^{\alpha}\Delta r^2}\left[\left(v_{ij+1/2}^{n} - v_{i-1,j+1/2}^{n}\right)r_{i-1/2}^{\alpha} - \left(v_{i+1,j+1/2}^{n} - v_{i,j+1/2}^{n}\right)r_{i+1/2}^{\alpha}\right]$$

$$(55)$$

can be written as

$$v_{i,j+1/2}^{n+1} = \xi_{i,j+1/2}^{n} - \frac{\Delta t}{\rho\Delta z}\left[P_{ij+1} - P_{ij}\right] , \qquad (56)$$

where $\xi_{i,j+1/2}^n$ represents the old velocity, advection, body force, and viscous terms in the v-momentum equation.

According to Chorin's derivation, the pressure and the advanced time velocity fields may be solved for simultaneously using the relationship

$$P_{ij}^{i+1} = P_{ij}^i - \Delta\tau \left(\vec{\nabla}\cdot\vec{v}^{n+1}\right)_{ij}^i \qquad . \tag{57}$$

The iteration scheme is as follows:

1. Equation (57) is used to compute a new pressure field.

2. The new pressure field is substituted into equations (54) and (56) to obtain the new velocities.

3. These new velocities are used to compute new values of the divergence.

4. Repeat the above sequence until some convergence criteria is reached. Note that $\eta_{i+1/2,j}^n$ and $\xi_{i,j+1/2}^n$ need not be recomputed at each interaction.

In order to maximize the time step, the iterates

$$\left(U_{i+1/2,j}^{n+1}\right)^{i+1}, \left(U_{i-1/2,j}^{n+1}\right)^{i+1}, \left(V_{i,j+1/2}^{n+1}\right)^{i+1} \text{ and } \left(V_{i,j-1/2}^{n+1}\right)^{i+1}$$

must be recomputed as soon as $P_{i,j}^{i+1}$ has been obtained for a cell, and before advancing to the next cell.

The pressures in boundary cells must be computed in a slightly different manner. Instead of adjusting the pressure proportional to the divergence or net flux out of a cell, it is adjusted proportional to the flux across the boundary relative to coordinates fixed in the boundary. This means that if liquid is flowing across the boundary the

pressure will be increased until the outflow stops. If liquid is
tending to separate from the boundary the pressure will decrease until
the liquid flows tangent to the boundary. This is accomplished through
the use of the following equation in boundary cells.

$$P_{i,j}^{i+1} = P_{i,j}^i - \frac{\Delta\tau}{\delta}\left\{\left[\left(v_p^{n+1}\right)^i - \vec{v}_b\ (r,t)\right]\cdot\vec{n}\right\}_{i,j} \tag{58}$$

Here $\vec{n}$ is the normal defining the boundary segment associated with
the cell (i,j), $V_b(r,t)$ is the velocity of the midpoint of the segment,
and $(\vec{v}_p^{n+1})^i$ is the liquid velocity at the midpoint of the segment. $\Delta\tau$
and δ are the relaxation parameter and the mesh width respectively. The
inclusion of the velocity of the boundary segment means that the boundary
not only can assume an arbitrary shape, but can move relative to the
computing mesh as well.

The capability of a boundary to assume an arbitrary shape and to
move within the computing mesh is of great use in the study of blood
flow problems. The flexing leaflets of the natural heart valve plus
the motion of the sinus of Valsalva in the aortic root area are examples
of needed flow calculations over objects whose boundaries undergo
large deformations. In turn, components of heart valve prostheses move
about in the computing mesh, requiring the same capability in the
computational technique.

Consider the computing region shown in Figure 8. Its shape
corresponds to the in-vitro experimental chamber of Weiting [9]. The
flow is from the left verticle, through the open valve, into the aorta.
Since the geometry of the valve is symmetrical about a line drawn
through its center, we can solve the problem by considering only one

DIRECTION OF FLOW **LEFT VENTRICLE** BALL **AORTA**
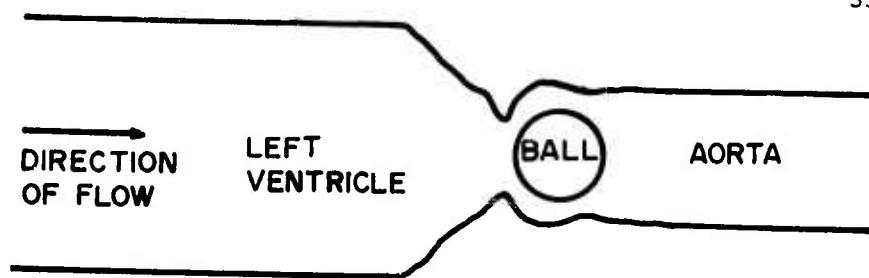
Figure 8

Mathematical Model of Aortic Valve
(Starr-Edwards 12-A)

half of the region. In Figure 9 the computational mesh has been placed

over the

half of the

computing

region we

wish to

consider,

and it has

been placed

in an r-z

coordinate
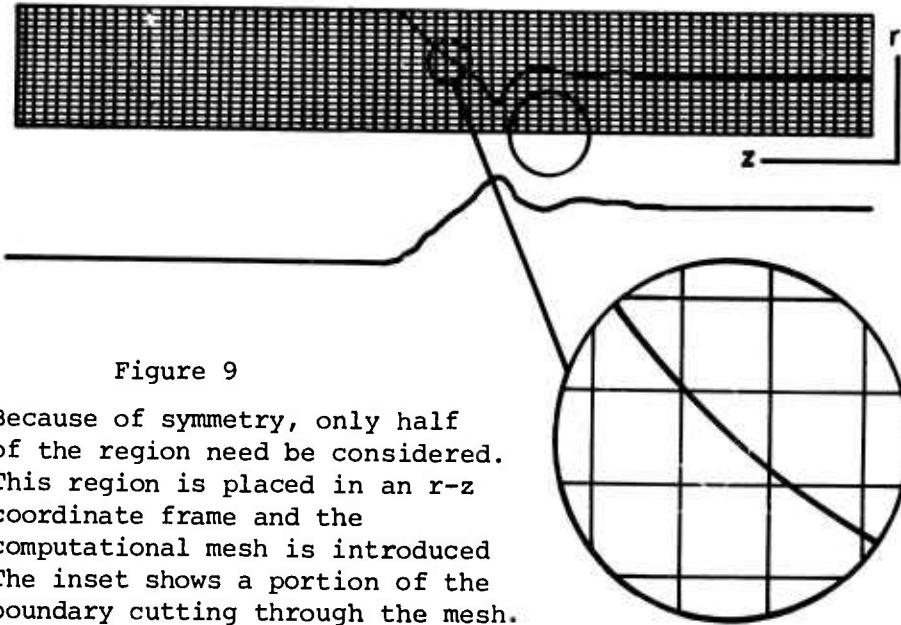
frame.

Figure 9

Because of symmetry, only half
of the region need be considered.
This region is placed in an r-z
coordinate frame and the
computational mesh is introduced
The inset shows a portion of the
boundary cutting through the mesh.

Looking at a portion of the boundary as it cuts through the

computational mesh, we can visualize the ABMAC technique for describing

an arbitrary, moving wall. In Figure 10a the boundary has been

approximated in each cell by a straight line connecting the intersections

of the boundary with the cell. The position of each segment is then

specified by a unit vector normal to the segment, with its base located

at the mid-point of the segment. The convention is that the normal

points towards the fluid, and to the left as one advances from the ith

to the $i+1^{st}$ boundary point. Also associated with each segment is a

velocity vector, defining the motion of the wall. In this study, such

velocity vectors would result from programming the pulsing motion of

the walls, and the motion of the ball as a result of pressure changes in

the system.
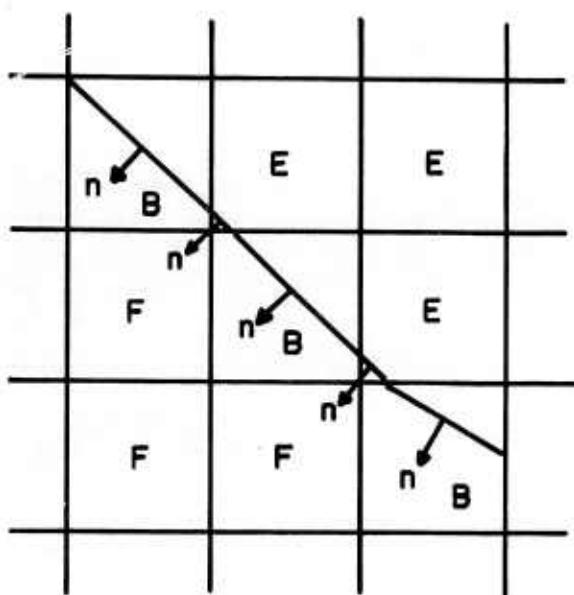
Figure 10a	Figure 10b
Boundary is approximated by straight line segments connecting the intersections of the cell walls with the boundary. Unit vectors normal to the segment and pointing towards the fluid are positioned at the midpoint of each segment.	When the liquid fraction of a cell is too small, the boundary flag is turned on in a neighboring cell. If that cell also contains a boundary segment, the two segments are replaced by one by removing the boundary inter- section between the two cells.
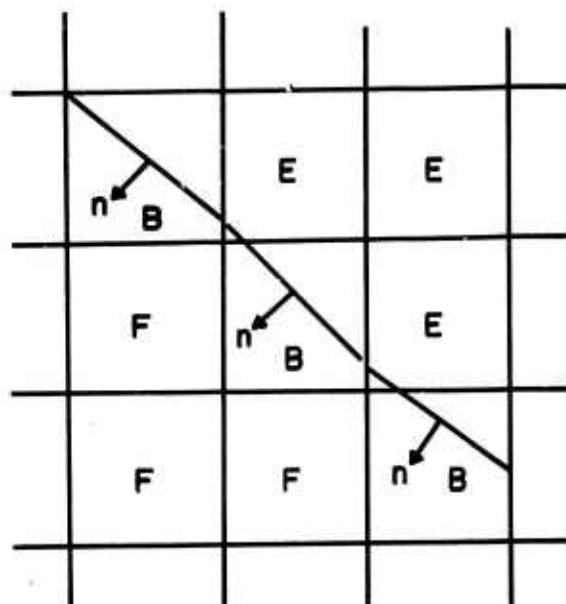
Having determined in which cells the boundary lies, the cells are

appropriately marked. Cells are marked as FULL, EMPTY, or BOUNDARY. The

boundary is approximated by flagging a boundary cell as such, only if

the liquid fraction of the total cell is greater than a specified fraction,
as shown in Figure 10a. If the liquid fraction is too small, the program
determines the neighboring cell that the boundary segment normal points
closest to, and turn on the flag for that cell. If that cell also
contains a boundary segment, the two segments are replaced by a single
segment, constructed by removing the boundary intersection between the
two cells. This is illustrated in Figure 10b.

Finally, marker particles are introduced to visualize the fluid
within the region. Figure 11 is an actual computer generated picture of
the completely described computing region.

Figure 11

Completely Described Computing Region
Including Marker Particles

CHAPTER FIVE

INTERACTIVE COMPUTER GRAPHICS

The cathode ray tube display was used as a computer output device
as early as 1956. The early Whirlwind computer at MIT used CRT displays
to plot curves and graphs. However, the first significant use of a CRT
display as an interactive device was demonstrated by Sutherland with
his Sketchpad program [24]. Sketchpad exhibited the two basic functions
of an interactive display device. First, it was used as an input/output
device that could accept or display data in pictorial form. Second,
it could be used to control the sequence of the program. Since this
demonstration of interactive computer graphics, it has been found to
be a valuable tool in many programming areas. Text editing [25],
conversational mathematics programs [26], circuit design [27],
mechanical design [28], and structural analysis [29], are some of the
areas in which interactive computer graphics has been found to be
useful.

Because fluid dynamics problems are extraordinarily complex, they
tend to absorb the computational power of available computing systems.
A single solution may consume several hours of CPU time on the most
powerful of today's machines. As advances are being made in numerical
methods, and in the understanding of the equations of fluid dynamics,
concurrent investigations must be made in developing newer and faster
computing techniques. The computer user needs to think of today's
computer as more than just a very big, very fast calculator. There are
many ways in which these machines can be used to create an effective

problem solving system. One such way is the addition of interactive

computer graphics.

The role that interactive graphics can be expected to play in the

study of fluid dynamics should be carefully evaluated before a large

scale commitment to computer graphics is made. One area for consideration

is the application of computer graphics to the display and interpretation

of results. Digital plotters have been around for many, many years,

helping computer users visualize their results. A picture may be worth

a thousand words, but in the case of computer generated data, a graph

or a plot may be worth over a thousand numbers. When working with a

real world physical problem, the computer user wants to see a real

world representation of his solution. He wants to see a picture, not

rows and rows of numbers.

A system where this kind of graphics is used interactively has

been proposed by Fromm and Schreiber [30]. Their approach has been

to have the program which computed the solution to the fluid problem

write a data set out onto a direct access storage device. Another

program, running interactively can then read the data, and under user

control provide a variety of interpretations of the data. A diagram

of this scheme is shown in Figure 12.

Especially applicable to Marker and Cell type techniques is the

making of motion pictures of the fluid simulations. A number of films

have been made [31,32] showing the power of such techniques. As the

marker particles are moved in each computational step, they are

plotted and photographed. The resulting sequence provides a most

graphic display of the fluid motion.
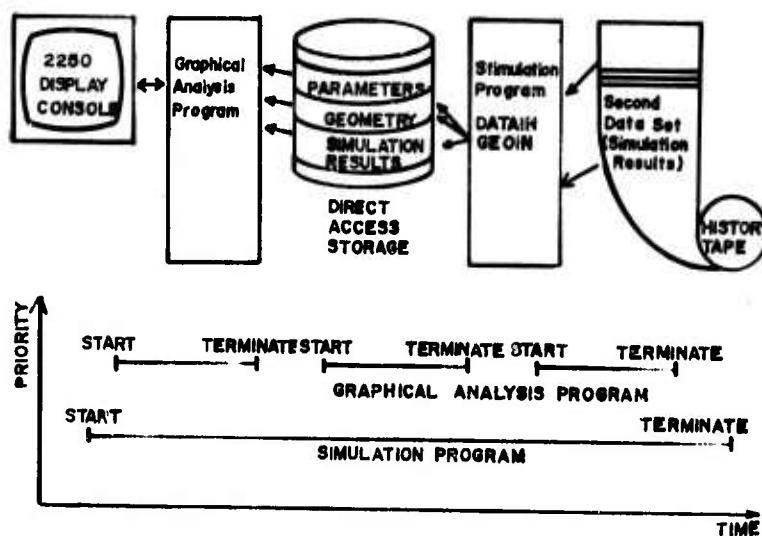
Figure 12

Graphic Analysis Program
(Fromm and Schreiber)

Another area in which it seems that graphics can easily be applied
is the description and input of the problem to the computer. Still
bound to ideas associated with batch processing, most problems are
carefully drawn out by hand, measured and detailed and the resulting
data punched into cards. It would seem much better to present the
computer the data in a more natural way, where the user could sit down
at an interactive graphics terminal, and draw the region in which a
solution would be of interest, specifying the various parameters as
the program requested them. In methods such as ABMAC where the
specification of boundary segments and the correct flagging of
computational cells is critical, the ability to quickly see the results
of the input andspecify the appropriate changes would seem to be very
desireable.

A third area worthy of attention is that of graphically monitoring
and interacting with the executing fluid computation. Although this

idea has been considered by previous investigators [33,34], it was not developed to its full potential. The basic idea is very simple. In any complex numerical problem there are several factors which can affect the solution to that problem. In a finite difference problem, these typically are the mesh size, the time step, and the relaxation factor. Other factors which may be of importance are the convergence criteria, the differencing technique, and the proper use of boundary conditions.

In working with problems in fluid dynamics, it becomes very apparent that no two problems are alike. Given the same initial conditions, the same boundary conditions, but changing the geometry of the problem even slightly, may mean that a whole new set of convergence criteria may be necessary to solve the problem. Perhaps one problem converges very quickly but one diverges unless a different time step is used. Each problem must be considered as a separate entity. Certainly dumps of pertinent numbers can lead the user to the correct choice of conditions to allow him to reach the correct solution. The question is how can this process of getting into the solution space of the problem be made more efficient. The obvious choice seems to be interactive computer graphics.

The interactive computer graphics facilities at the University of Utah consist of a PDP-10 time shared computer running under Tenex, a PDP-9 computer, four Univac 1559 CRT displays, and the associated hardware interfaces. Figure 13 shows the basic configuration of the system.
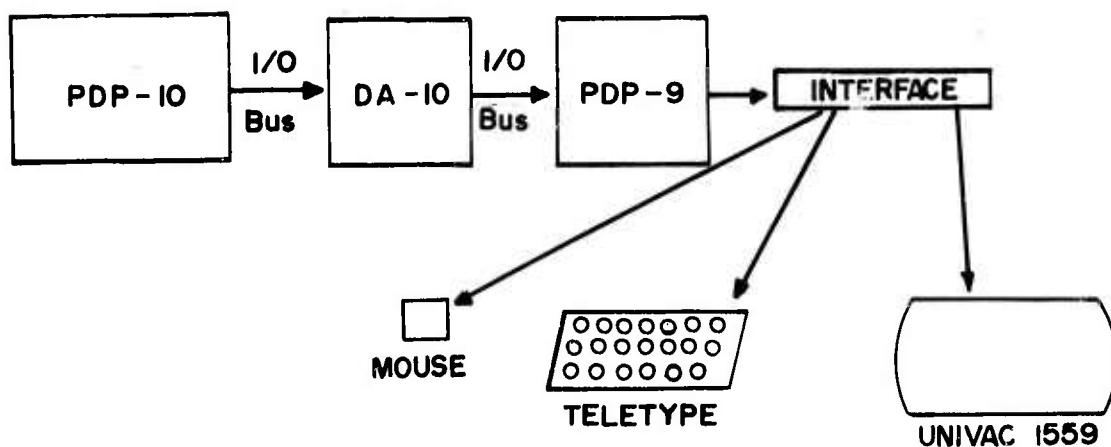
Figure 13

Configuration of Interactive Graphic System
at the University of Utah

The PDP-10 is a 36 bit machine. It has sixteen high speed

integrated circuit registers which can be used as accumulators,

normal memory, and/or index registers. The memory bus structure of

the PDP-10 gives the central processor and high speed data channels

simultaneous access to separate memory modules. The bus system allows

each data channel to transmit full 36 bit words at speeds of up to

one million words per second.

In conversational time sharing, up to 63 users at local and

remote locations can simultaneously develop programs on remote

consoles, and receive answers to mathematical or engineering problems

in seconds. The time sharing monitor provides instantaneous response

for the users, so that they can perform on-line composition, editing,

and debugging of programs in FORTRAN IV, MACRO-10, BASIC, and AID.

The monitor can handle any mixture of these languages and programs

concurrently.

The PDP-10 at the University of Utah is configured with 96,000 words of core storage, 8 dec-tape drives, and 6 disk pack drives. Each disk pack is capable of holding over 5 million words of information.

Attached to the PDP-10 through the DA-10, a communications device, is the PDP-9. The PDP-9 is a single address, fixed word length (18 bits), binary computer. The configuration here has 8,192 words of memory. The function of the PDP-9 is to act as a satellite computer to the PDP-10. It processes interrupts from the displays gathers data to be sent to the PDP-10, and acts as a multiplexor for display information coming from the PDP-10.

The Univac 1559 is a high speed, buffered, line drawing display which was designed as a cooperative exercise between the University of Utah's Computer Science Department, and the Univac Division of Sperry Rand Corporation. The Screen of the 1559 has a useful viewing area of 10" by 10". Positions on the screen are specified in cartesian coordinates, in which the origin is placed at the bottom left hand corner of the screen. The top right hand corner is the point (1024, 1024).

Display files are held in the displays own memory, a 4096 by 16 bit core memory with a cycle time of 1.4 microseconds. The 1559 has its own program counter, called the list counter, which is used to access sequential display instructions.

All lines are drawn on the screen in a relative mode, i.e., they are defined by their length in the two axis directions, and are drawn from the position currently defined in the X and Y registers. The time taken to display a normal vector is 2 microseconds. Beam repositioning takes 32 microseconds or less, depending upon the distance involved.

Associated with each display is a mouse, and a teletype. The mouse is a çraphical input device, consisting of a small plastic box in whose base two potentiometers are mounted. The mouse rests on two metal wheels, whose axes are horizontal and at right angles to each other. Each wheel is connected to one potentiometer. As the mouse is rolled around on a flat surface, its movement in two orthogonal directions is reocrded by the rotation of the potentiometers. This can be determined by applying a voltage across each potentiometer and sampling the outputs through analog-to-digital converters. Push buctons on the mouse give the user the ability to issue commands from the mouse under program control.

CHAPTER SIX

GRAPHICS INTERACTION FOR THE ABMAC PROCEDURE

Regardless of how sophisticated the application may be, if the graphics and interaction code are poorly handled it is difficult to justify their use. Whatever advantage may be gained through the addition of interactive graphics can be completely offset because of poor program design. In the kind of application being considered here, there are two glaring problems which must be considered. First, any problem involving finite differences is typically very large. In a time sharing environment such as the one being used here, any increase in core size becomes critical to the effective running of the machine. Second, fluid computations absorb a great deal of computing time. A solution may take more than 30 hours of computing time to complete. For this reason, the time required for interaction and graphics should not interfere a great deal with the actual computation time.

Work done by Carter [33] and Bennion [34] here at the University of Utah is typical of the approach which has been used in implementing interactive graphics in a large scale numerical application. Figure 14 illustrates the way in which this approach imbeds the interactive and graphics code within the computational program. This implies several drawbacks in light of the problems under consideration.

First, at each point in the computational program where one of these imbedded pieces of interactive graphics occurs, there must exist a sequence of code represented by the flow chart in Figure 15. This adds a certain amount of program space to the already large finite
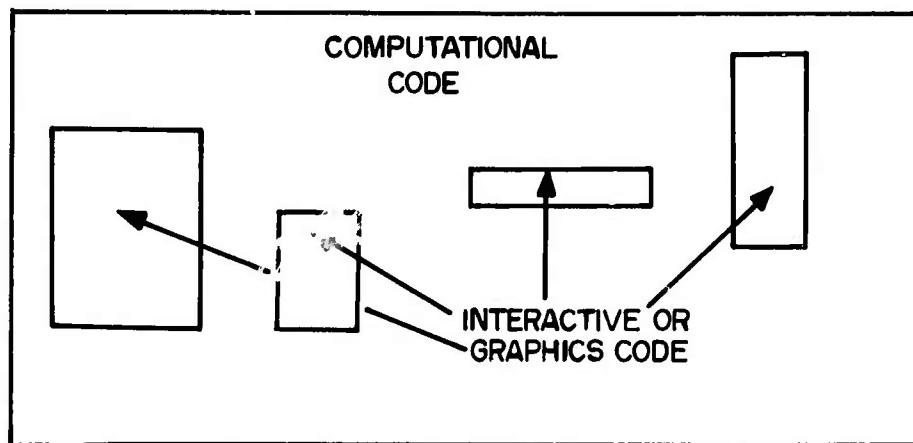
Figure 14

Schematic of Imbedded Interactive Graphics Code

difference code, and requires the program process this overhead each time that it is encountered. Suppose that some code of this nature was placed in an iterative loop, and that that loop was iterated through a hundred times per time cycle. That would represent a large amount of overhead in a program where computing time was already critical.

Second, consider what takes place when a display is required. Since dynamic events are being modelled, each time an additional piece of information is required to be displayed, a piece of code is needed to describe that display. This means that there will be an additional amount of program which will be proportional to the complexity of the display both in terms of space and the time needed to execute it. As the number and complexity of displays increases, the size of the

program grows, and the time required to display is taken from the total computation time.
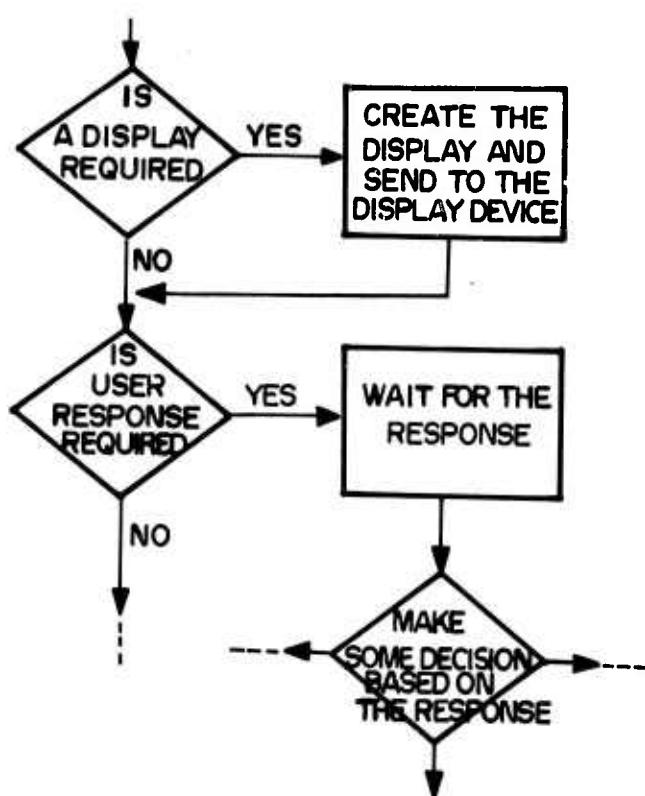
Figure 15

Flow Chart for Imbedded Interactive Graphics

Third, consider what occurs when some user interaction is required. Whenever the program expects a response from the user, it must stop and wait for that response. When the response is received, the program must make some decision or perform some branching based on the response. Again, what this means is that the more often interaction takes place, the more code the program needs, and the more time the program loses to computation.

The proposed solution to these problems is simple; remove the interactive graphics from the program. At first this may appear to be a contradictory statement. How can an interactive graphics system be written for solving a problem, when the computational program has no interactive graphics. By splitting up the program as shown in Figure 16 , the solution becomes easy.
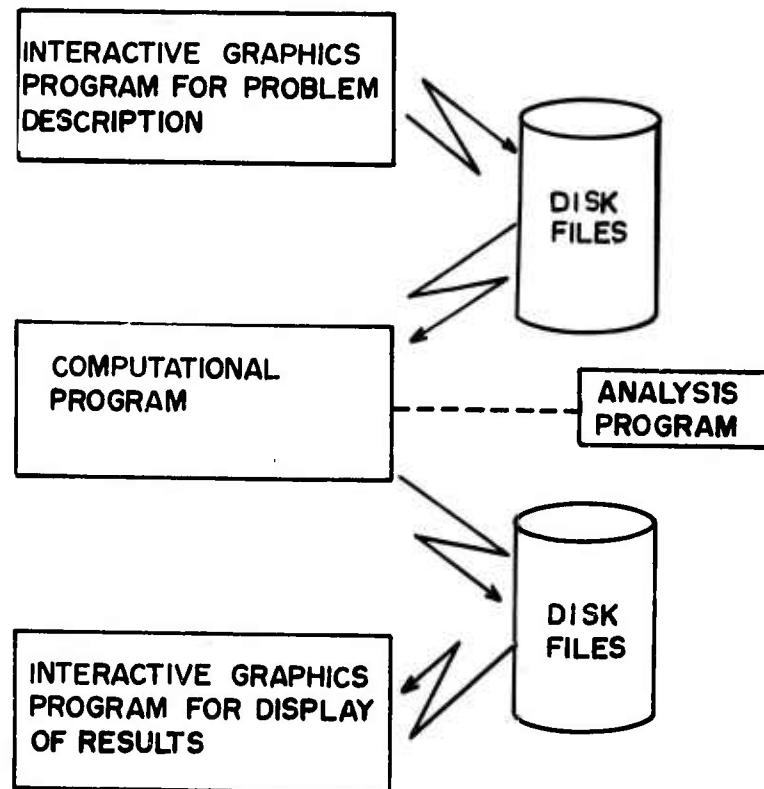
Figure 16

Formation of Supplemental Programs

This system allows the investigator a great deal of freedom in describing his problem to the computer. His input is not bound to certain fields on punched cards, but can be more naturally input as he manipulates figures on the face of the CRT. In this type of environment he can alter the problem description and have immediate visual feedback

of the changes he makes, and computation need not proceed until he is

satisfied with the problem he has described. A term that is often

heard in the computer community is "structured programming" [35].

In large software systems such as assemblers, compilers and operating

systems, people try to structure their programs in a nice way. However,

in the scientific world, it seems that this idea is often neglected.

In the system under consideration, it seemed that a very highly

structured program was a necessity. First, it is desirable to keep

the computational routines and the display routines completely

separate, and yet they must be able to communicate with each other very

freely. Also, the graphics routines themselves must be structured in

such a way as to allow the user the greatest possible degree of flex-

ibility, and yet be simple to understand and use. These considerations

pointed to the necessity of a modular program for implementing a

graphical ABMAC technique.

In quantizing the program, it seemed appropriate to study the

nature of the problem which it was intended to solve. Basically, the

solution consists of three components; describing the problem, solving

the problem, and displaying the solution. This is illustrated in

Figure 17.
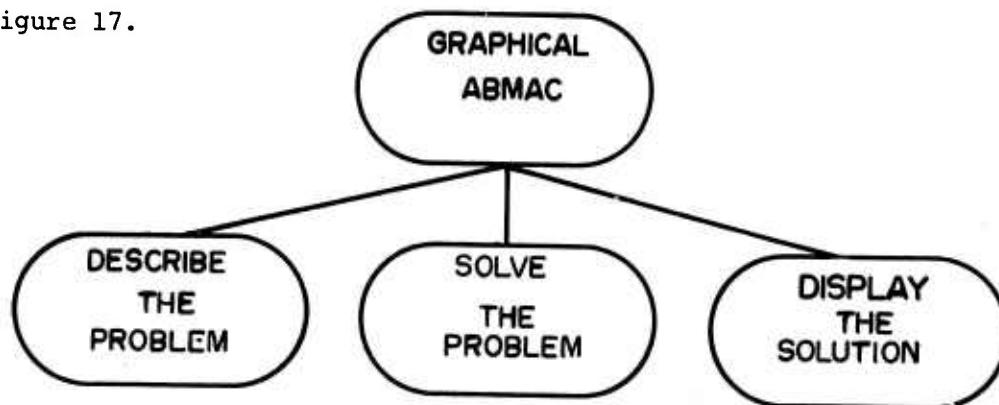
Figure 17

Basic Components of a Graphical ABMAC Program

A.   DESCRIBING THE PROBLEM

The problem description can be broken down into four different
components; setting the initial values of computational parameters,
describing the computational grid, describing the geometry of the
problem, and describing initial and boundary conditions of the fluid.
These steps are shown in Figure 18.
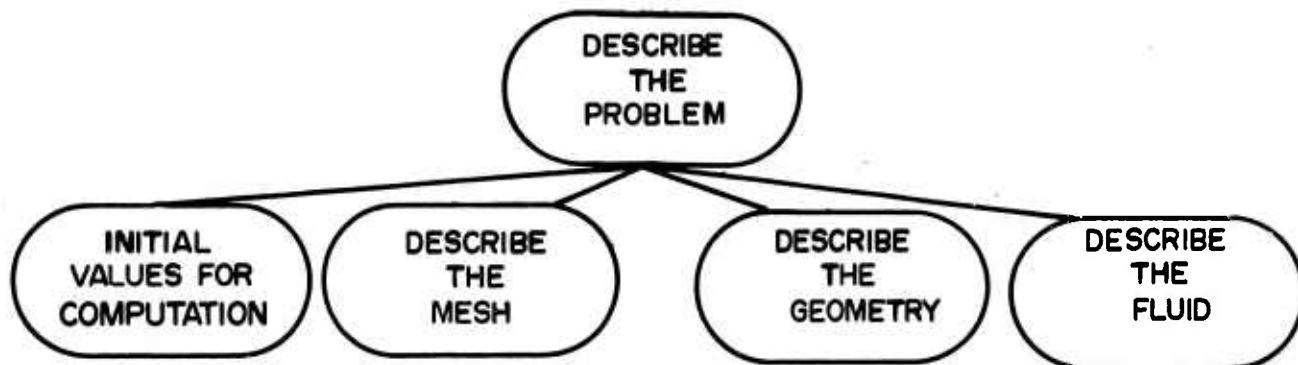
Figure 18

Components of Problem Description

Each of these components can be broken down even further into
functional groups. It is at this level that the program was structured.
For example, consider the mesh description. This requires four
functional groups: a main or controlling program, a program to handle
communications with the user through the teletype, a display program
to give visual verification of entered values, and a routine to computer
various scale factors and constants for later use. The actual grid
is displayed in another set of programs.
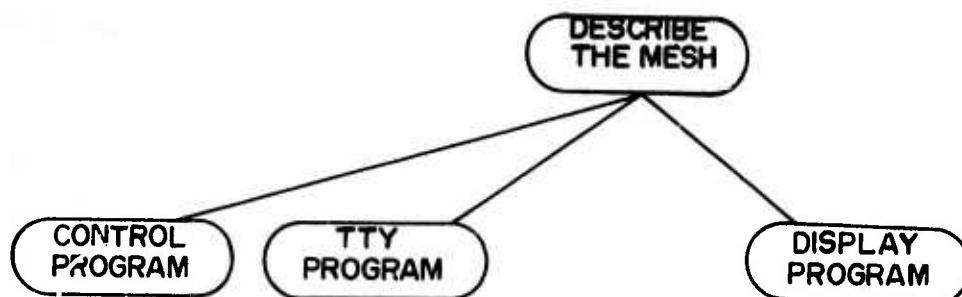
Figure 19

Components of Mesh Description

The entire system then takes on a tree-like structure. Putting

the pieces together as described above gives the structure of Figure 20.
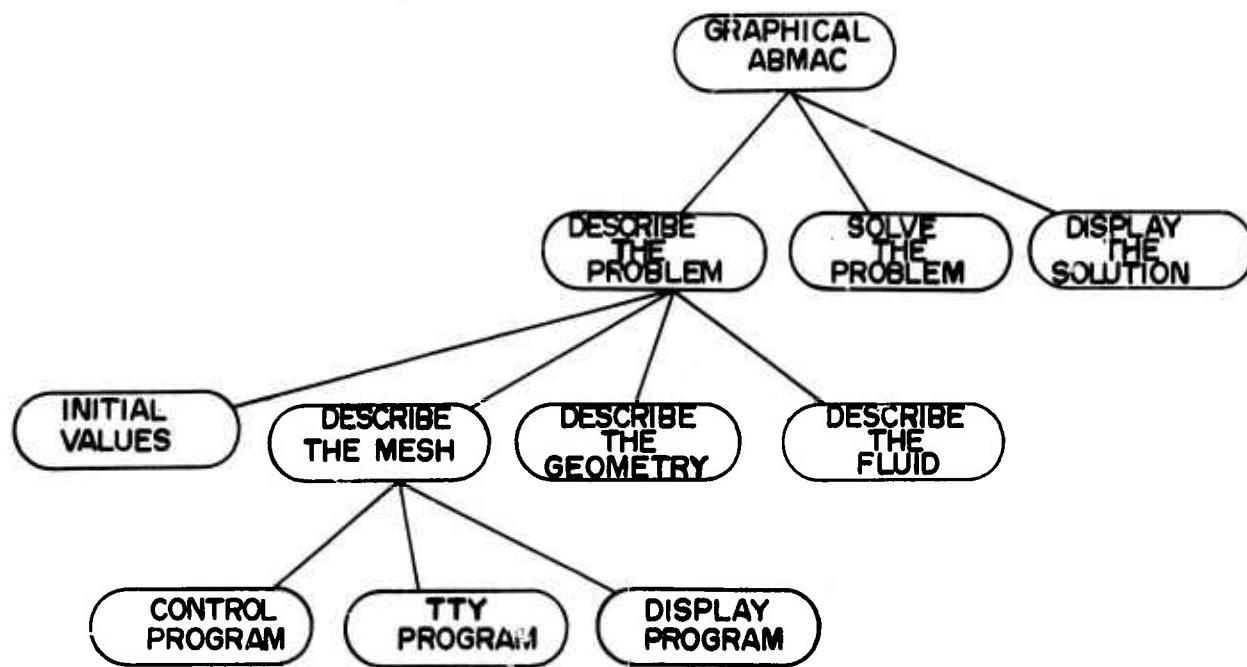
Figure 20

Tree Structure of Graphic ABMAC Components

This kind of structure makes the code simple, easy to understand, and interactive to a high degree. The following section will point out some of these ideas, as the basic components of the program are discussed in detail.

The Main Program

The main program in the input routines simply allows the user to choose the type of input he wants to use. After initializing the display system, the main program produced the display shown in Figure 21. By pointing to one of the boxes shown, the appropriate input program is called. "TTY" and "DSK" allow the user to input all of his data from the teletype or from a previously constructed disk file. If he points to "TERMINAL", the graphical input program is called and executed.

INPUT FROM:

[TTY]

[DISK]

[TERMINAL]
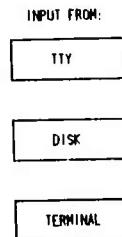
Figure 21

Initial Graphic ABMAC Display
for Choosing Input Device

The Input Module

This module is the actual driving module for the input programs. It gives the user complete control of the input for his particular problem. In order to provide the user with some guide for constructing his problem description, the input module produces the display shown in

Figure 22. This display lists the various functions performed in a typical problem description. The user steps through this list by pointing to the function which he wishes to perform next. As he points to an item he pushes one of the switches on the mouse. This indicates to the program which function is desired. That program module is then called to be executed. When it is finished control returns to the input module. The basic structure of the input module is this:
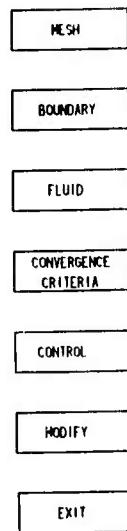
Figure 22

Computer Display for Graphic
ABMAC Problem Description

```
1       CALL INPUT1
        CALL WMOUSE
        INY=(INY+128)/128
        GO TO (2,3,4,5,6,7,8)INY
        CALL CHECK
2       CALL OUTP
        CALL EXIT
3       CALL MOD
        GO TO 1
4       CALL CNTRL
        GO TO 1
5       CALL CONVG
        GO TO 1
6       CALL FLUID
        GO TO 1
7       CALL FIGURE
        GO TO 1
8       CALL MESH
        GO TO 1
        END
```

INPUT1 is the program which creates the display of Figure 20. WMOUSE
is a program which halts the computer until one of the mouse switches
is pushed. It then returns the coordinates of the mouse cursor in the
variables INX and INY. This is how the mouse is used in pointing to
objects on the display screen. By performing a transformation on INY
and using a computed GO TO statement, the input module calls the
appropriate subroutine. As each subroutine returns, a GO TO 1 is
encountered which creates the list of functions again and waits for the
next user response.

The light buttons produced by INPUT1 are created in a program called
BOXES. The number of boxes desired is passed as an argument to the
subroutine. It computes the correct starting position for each box,
and then calls another subroutine named BOX which draws the actual
box in that location.

The Mesh Description Module

This module allows the user to specify the computational mesh
upon which he wishes to solve his problem. The way in which this is
done illustrates another unique feature based on the structuring of
the program. It is desireable to ask the user to input all of the
required parameters, so that none are forgotten. Once this is done the
program should allow him to selectively change any of the input values.
This is accomplished using a driving routine for this module which
looks like this:

```
        DO 1 I=1,5
    1   CALL MESH1(I)
        CALL WMOUSE
        INY=(INY+128)/128
        IF(INY.GE.6)RETURN
        CALL MESH1(INY)
        END
```

and MESH1 looks like this:

```
              SUBROUTINE MESH1(J)
              GO TO (4,6,8,13,15),J
    4         TYPE 5
    5         FORMAT(1H ,'DR=',$)
              ACCEPT 3, DR
    3         FORMAT(F)
              GO TO 18
    6         TYPE 7
                 .
                 .
                 .
   18         CALL MESH2
              CALL SEND
              RETURN
              END
```

As the module executes, the following sequence of events occurs. MESH1 is called 5 times, each time with a different argument. This argument determines which of the parameters is to be requested from the teletype when the value is typed in. Control is then passed to MESH2. MESH2 puts up the display shown in Figure 23. Each time the display is produced, it shows the most recent values of the input mesh parameters.

Having gone through all of the mesh parameters in the DO LOOP, the driving routine calls WMOUSE in the same manner as in the control module. This way the user can point to a value he wants changed, and push the mouse switch. This calls MESH1 with the appropriate argument to change that value. If he points to the top box, control returns to the input module.

RETURN

NO. OF CELLS
IN Z = 82

NO. OF CELLS
IN R= 18

CYL COORD

DZ=0.2000

DR=0.2000

Figure 23

Computer Display for Graphic
ABMAC Mesh Description

Figure Description Module

The purpose of this module is to allow the user to input the geometry of his problem in a natural way. Initially the module creates the display shown in Figure 24.

Pointing to INFLOW directs the program to accept the inflow boundary conditions of the problem. Pointing to BOUNDARIES directs the program to accept the geometry of the problem. A program called FIG3 controls the input on the geometry. Its first task is to create the display shown in Figure 25. This is a display of the computational mesh previously described. The coordinate axes, the number of cells in the mesh, Dr, and DZ are also displayed. The program is capable of accepting the input describing the figure either from the teletype or the mouse. As each point is entered, an arrow head is created and displayed, showing the location of the point. A completely described digure is shown in Figure 26. At the conclusion of executing this module, the completed figure is created and displayed without the mesh, as shown in Figure 27. This figure is seen to be equivalent to half of the region of interest shown in Figure 8. Because of symmetry only half of the region need be considered. If the display produces a satisfactory drawing, control returns to the input module.

BOUNDARIES

INFLOW

RETURN
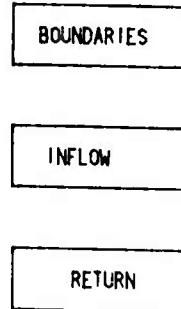
Figure 24

Computer Display for Graphic
ABMAC Figure Description
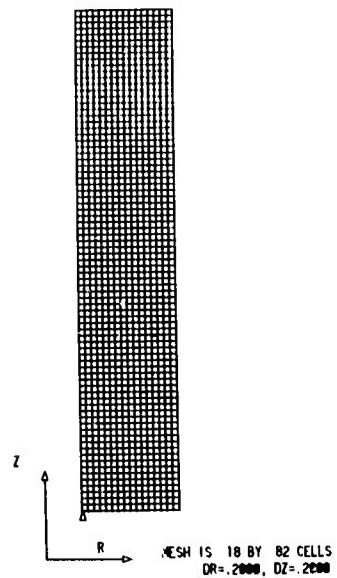
Figure 25
Computer Display of Computational Mesh
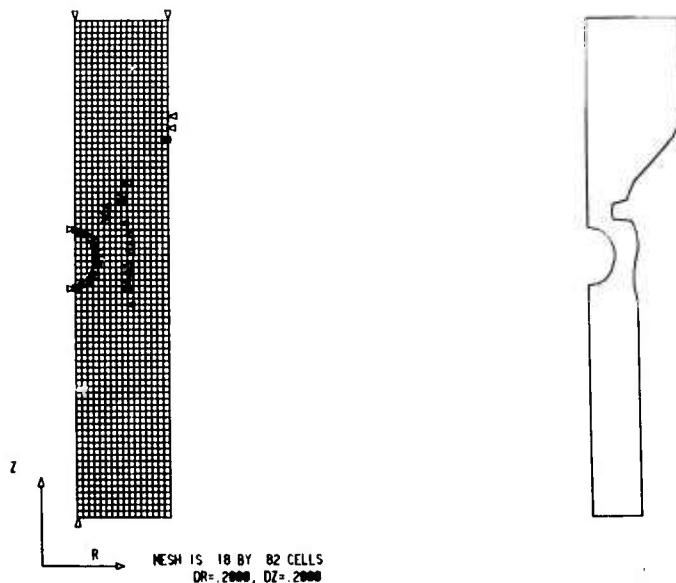
Figure 26

Computer Display of Computational
Mesh Showing Points Input to
Describe the Curved Boundary

Figure 27

Computer Display of Final
Figure Description

The Fluid Description Module

This module accepts the initial
conditions which are to be imposed on
the fluid. Using the display shown
in Figure 28, the fluid description
module operates in the same manner
as the mesh description module. The
variables input here include MU; the
kinematic viscosity of the fluid,
RHOA; the denisty of the fluid, NP,
the density of the marker particles,
V, NOT; the initial V-velocity, and
U-NOT; the initial U-velocity.

| RETURN |
| MU=0.0032000 |
| RHOA=1.060000 |
| PARTICLE DENSITY = 2 |
| V=-10.000 |
| U= 0.000 |

Figure 28

Computer Display for Graphic
ABMAC Fluid Description

The Initialization Module

This module has been split into two different parts. The first
handles the input of the problem
parameters effecting convergence.
The list of parameters is shown in
Figure 29. DT is the time step, EPS1
is the convergence epsilon, and BETA
is the relaxation constant. Input of
these numbers is done just as in the
mesh description module.

| RETURN |
| BETA=0.450 |
| EPS2=0.00010 |
| DT=0.00050 |

Figure 29

Computer Display for Initializing
Convergence Parameters

The second portion of this module
handles the input of those parameters
effecting program control. These are
shown in Figure 30. NDUMP is the number
of cycles between creations of saved
core images, NPIT is the number of pressure
iterations allows per cycle, NSTOP is the
number of cycles to be run, and NEDIT is
the number of cycles between EDITS. FNAME
is the name of the file to be created with
the output of this program, and description
is a short description of the program
which has been described. Input is done
in the same way as above.

| RETURN |
| DESCRIPTION |
| FNAME=BALL |
| NEDIT=20 |
| NSTOP=500 |
| NPIT=24 |
| NDUMP=20 |

Figure 30

Computer Display for Initializing
Control Parameters

When the EXIT function is requested, the input program calls upon
two remaining subroutines. Although they serve important functions,
they were not included as separate modules. The first of these is the
CHECK routine. This produces the display shown in Figure 31. This is
a complete description of the input problem. The mirror image of the
description is rproduced across the Z-AXIS, and the dimensions are
labeled. Also shown are the initial and input velocities, and the
text describing the problem. If this description is what the user
wants, he pushes the switch on the MOUSE, and the various parameters
describing the problem are written out onto a disk file. This is done

using the subroutine OUTP. This routine organizes the data and writes

it out in the form expected by the ABMAC routines.

STARK-EDWARDS BALL VALVE...
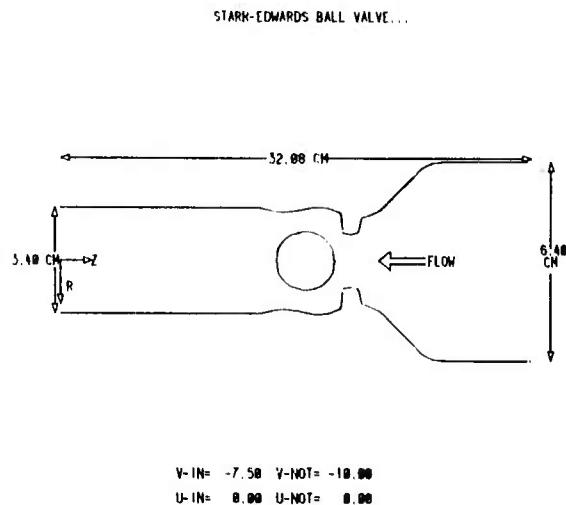
Figure 31

Computer Display of Complete Problem Description

B.   SOLUTION OF THE PROBLEM

The use of interactive graphics in numerical problems was briefly

discussed in the previous chapter. One area under consideration was

the use of interactive computer graphics to monitor and interact with

the computational program. The computational code in this program is

based on Viecelli's ABMAC technique. Typical of finite difference

methods, it is very large. The addition of an arbitrarily shaped

boundary adds even more complexity to the program. If the design

goals of an efficient program are to be met, this program cannot contain

any code to do interactive graphics. It is still possible however, to

graphically monitor and interact with the computational program.

The structure of the TENEX system on the PDP-10 allows two jobs to simultaneously share core. Using this facility, a program can be constructed which "SPIES" on the computational program, and visually displays what the computation is doing. This method of applying' interactive graphics has the following advantages:

1. The spy program is completely independent of the computational program. Small and compact, it adds no apparent load to the overall computer system.

2. The computational program, running independently of the spy program can run completely in the background, being detached from any 1/0 device.

3. The Spy program need only be run when desired. Its presence puts no additional load on the computation program.

4. The computation program has none of the overhead normally associated with graphics or interaction.

5. Since the data space of the computational program is available to the spy program, parameters effecting convergence or program control can be changed from the spy program.

The mechanics of core sharing are straightforward. During the initialization process in the computational program, the user has the option of requesting that a shareable file be created. At this point,

a file is created, and opened. Then pages from the fork containing the computation program are mapped into the file. The computational program is now free to run uninterrupted.

Whenever it is desired to examine the state of the computational program, the spy program is run. The spy program immediately maps into its own fork (or processing space) pages from the file created by the computational program. Whatever pages have been mapped in this way are actually now being shared by the two programs. This is illustrated in Figure 32.
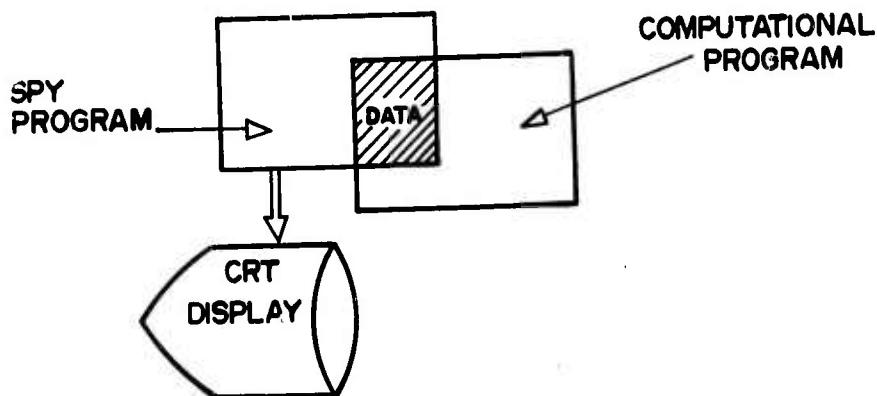
Figure 32

Block Diagram of Core-Sharing Used
to Achieve Interactive Graphics

The spy program then creates the display shown in Figure 33. This display presents to the user important information about the state of the computation. In the center of the display are shown the cycle number and the iteration number in that cycle. The display is dynamic in the sense that these numbers constantly change to reflect the current state of the computation.

MAX CHANGE IN U= 25.258
MAX CHANGE IN V= 31.208

THIS CYCLE
MAX PRESSURE=44340.073
MAX V-VELOCITY= 168.928
MAX U-VELOCITY= 113.029

EPS=0.0001000

BETA= 0.50000

NPIT = 24

DT=0.000500

SELECT

CYCLE 279
ITER 5

MAX DIVERGENCE

ENORM/PNORM
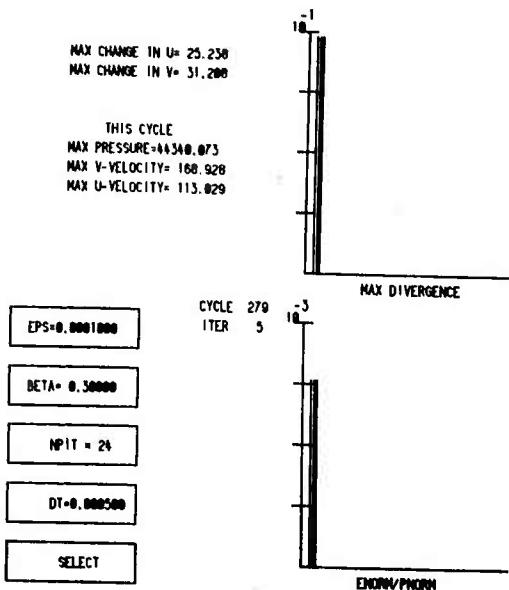
Figure 33

Computer Display of Current State of ABMAC
Computation as Produced by Spy Program

In the upper left hand corner of the display are shown the maximum
changes in the velocity components as measured during the current
iteration. As the problem converges, these values will approach zero.
In order to give additional meaning to the changes in velocity, the
maximum values of the velocity components as well as of the pressure
are displayed for the current cycle.

On the right hand side of the display are shown plots of the
divergence and the error term for the pressure iteration. Bars are
added to this plot at each iteration, so that the convergence or
divergence of the iteration sequence can be monitored. The divergence
is given in equation (1). As is shown, it is required that the
divergence be equal to zero. In terms of the finite differences, this
will never exactly be true. However, it should approach zero. The
error term in the pressure iteration is

$$\text{ERROR:} \quad \text{PNORM/ENORM,} \tag{59}$$

where

$$\text{PNORM} = \sum_i P_i^2 \tag{60}$$

and

$$\text{ENORM} = \sum_i \Delta P_i^2 \tag{61}$$

The spy program is constructed so that it sleeps as long as there is nothing new to display. When a change occurs, it wakes up, makes the appropriate changes or additions to the display, and returns to a sleep state.

Along the left hand side of the display are five light buttons. The first four of these are parameters which affect the convergence of the program. By pointing at any one of these with the mouse, it is possible to change the value of that parameter in the computational program. EPS is the convergence epsilon, BETA is the relaxation constant, NPIT is the maximum number of allowable pressure iterations per cycle, and DT is the time step. The bottom light button, marked SELECT, gives the user some control over the course of the computation.

Pointing at the SELECT light button results in the display shown in Figure 34.

```
┌──────────┐
│   EXIT   │
└──────────┘
┌──────────┐
│   DUMP   │
└──────────┘
┌──────────┐
│  PRINT   │
└──────────┘
┌──────────┐
│  CYCLE   │
└──────────┘
┌──────────┐
│   STOP   │
└──────────┘
```
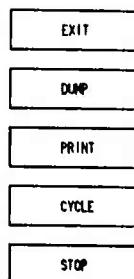
Figure 34

Computer Display of Spy Program Options

This display gives the user five options from which to choose. By pointing the mouse at one of the light buttons, flags are set in the computational program which set into motion the appropriate action. STOP sets a flag which causes the computational program to stop at the end of the current cycle. Before stopping, it will create a data file and a core image of itself. CYCLE sets a flag which causes the current iteration sequence to stop, and a new cycle to be started. PRINT causes a data file to be constructed at the end of the current cycle. DUMP causes the program to create a file which is a core image of itself. This file can be used as a starting place for continuing the program. EXIT halts the SPY PROGRAM without affecting the computational program.

These few capabilities provide all of the necessary interaction for this kind of a problem, and because of the way in which they are implemented, the computation procedure does not suffer from the problems associated with interactive graphics.

C.   DISPLAYING THE SOLUTION

Using the computer to produce graphical images of a solution has become a well understood idea. Digital plotters, microfilm plotters, and CRT displays have given the computer user an important tool to help him solve his problems. Working with a visual representation of his solution he can gain valuable insight into his problem.

The program for displaying the solutions has three basic functions. The first is to read in the data from the disk files. Two files are required for displaying solutions. The first file which is needed is the file containing the problem description. This is used in drawing the curved boundaries for plotting solutions. The second file is the

data from the computational program. It should be noted here that all of the filenames are handled internally by the various programs. A master file name is all that is required in order for any program to get the required file from the disk.

The second function of the program is to compute the A matrix, the BNDRY matrix, and the SI matrix. The A matrix and the BNDRY matrix are matrices which are used in the countour plotting program. This program plots contours inside of arbitrarily shaped boundaries. The A matrix and the BNDRY matrix are used in specifying the boundary to the contour program.

The third function of the program is to produce displays of the solution space. Control over this function is similar in nature to the control of the input program, using the mouse and a computed GO TO statement to govern the branching. The display of figure 35 is drawn by the subroutine CNTRL1. These light buttons indicate the available functions for displaying the solutions to the problem. By pointing at one of these light buttons with the mouse, the appropriate type of solution will be displayed on the screen. Although the option for producing an isometric plot is shown, and a program for doing so is available, technical considerations made it impossible to include isometric plots of solutions in this report.

Figure 35

Computer Display of Output
Functions.

Velocity Profiles

Velocity profiles can be drawn for any specified axial position. Initially the display shown in Figure 36 is drawn on the screen.
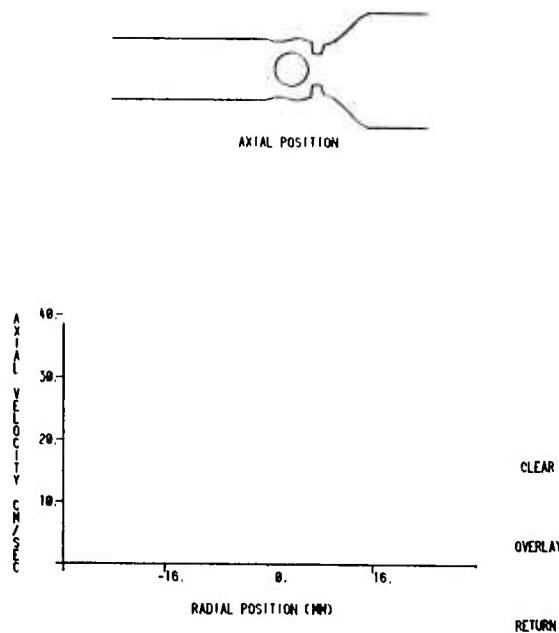
Figure 36

Computer Display of Basic Plot
For Velocity Vector Display

The horizontal and vertical axes are the radial position in millimeters, and the axial velocity in centimeters per second, respectively. On the right side of the screen are three light buttons. CLEAR causes the entire display to be erased, and the display of Figure 36 redrawn. OVERLAY allows more than one velocity profile to be displayed at the same time. RETURN returns control to the control portion of the main program. At the top of the display is a scaled down drawing of the geometry of the problem. As each velocity profile is drawn on the

display, a small arrow head indicates the axial position of that profile

by pointing to the appropriate position on the scaled drawing. The

display in figure 37 contains one velocity profile at the axial position

AXIAL POSITION
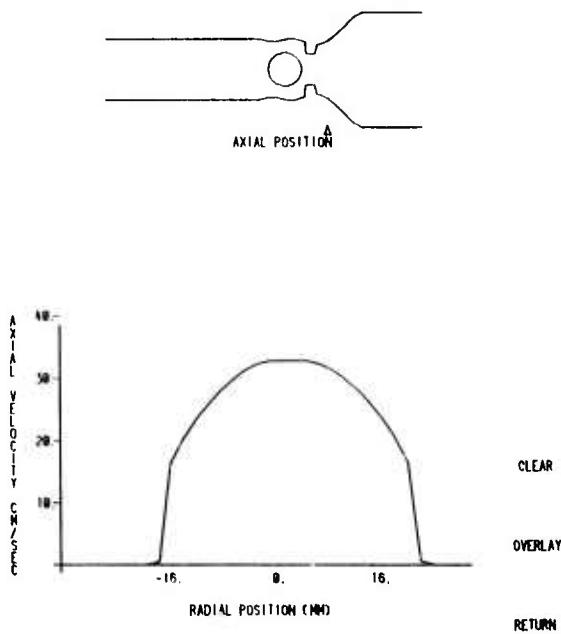
Figure 37

Computer Display of a Typical
Velocity Profile

shown. All of the programs in this section were written to serve one

purpose. That is to give the user a quick look into the solution of

his problem. Because of this, they do not contain a lot of code

required to produce "beautiful" pictures. For example, in the velocity

profiles as displayed above, no data smoothing has been attempted. The

plot shown merely connects existing data points. The display shown in

Figure 38 illustrates the ability to produce a series of velocity

profiles in the same display. This type of display is meaningful in

that it shows the development of the flow as it proceeds down the length of the tube.
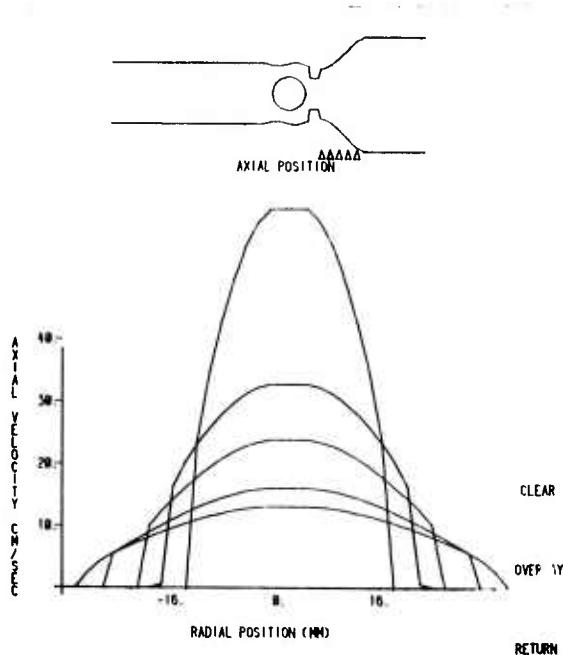
Figure 38

Computer Display of a Series
of Velocity Profiles

Contour Plots

The initial display of the contour plotting program is shown in Figure 39. The user points the mouse at the light buttons on the right side of the display in order to choose the variables which he wants contoured. After doing this, he uses the mouse to outline the region he is interested in seeing onthe figure to the left of the light buttons. This allows him to "zoom in" on areas of particular interest. As the region of interest is narrowed down, the number of contour levels can be increased so that more detail is visible. Figures 40, 41, and 42 illustrate this effect on a contour plot of the stream function.

STREAM
FUNCTION

PRESSURE

U-VELOCITY

V-VELOCITY
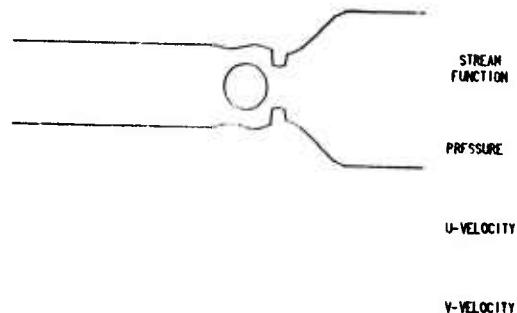
Figure 39

Initial Display for Contour Plotting
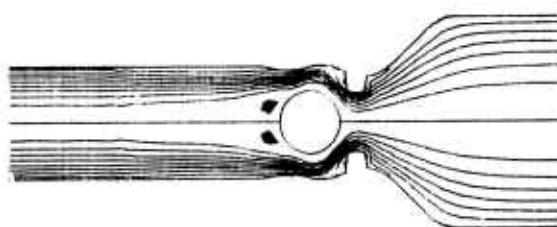
Figure 40

Computer Display of Stream Function
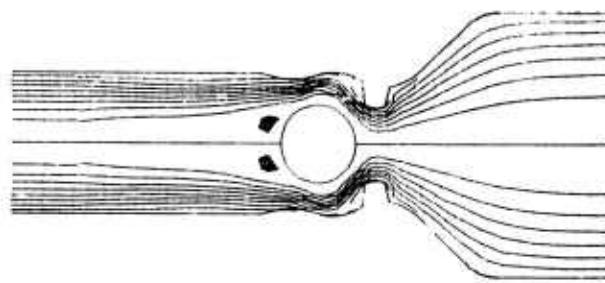
Figure 41

Computer Display of Same Stream
Function under a Different Window
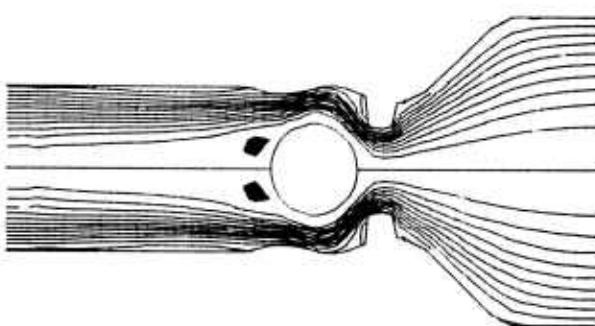
Figure 42

Computer Display of Same Stream Function
Under an Even Smaller Window, Illustrating the Zoom Effect

This zoom effect is done with a graphic technique known as "windowing." Windowing is the process of defining a region of interest and mapping it onto a particular area of the display screen. This technique is illustrated in Figure 43.
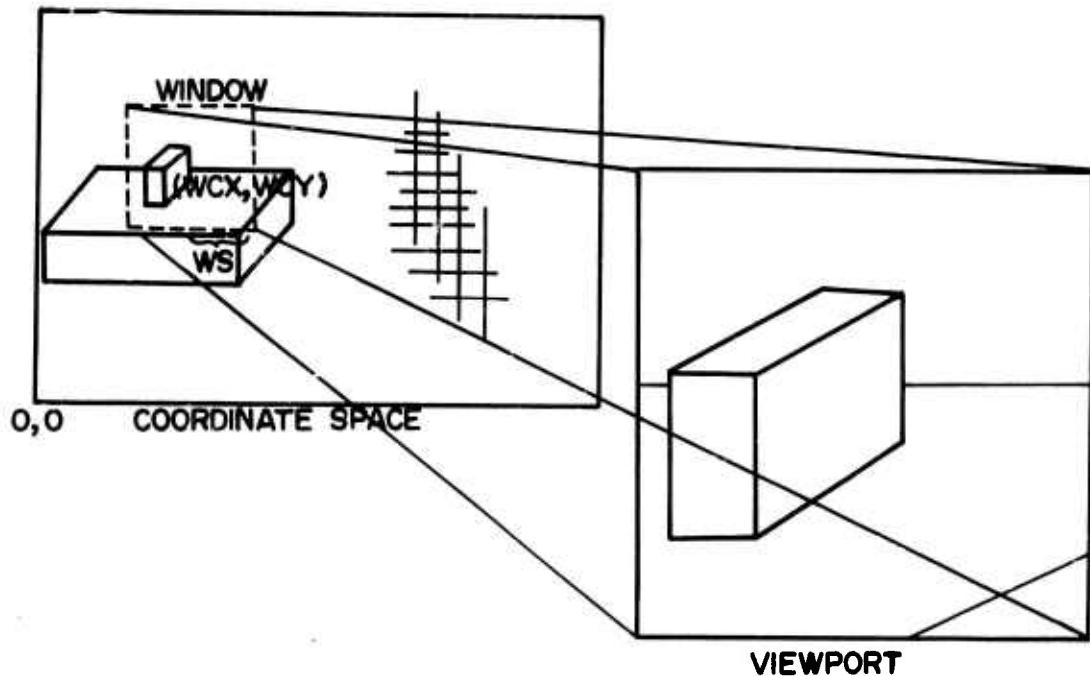
Figure 43

Mapping Function Performed by Windowing

If WCX and WCY are the coordinates in the coordinate system of the problem, of the center of the window, and WS is the measure from the center to one side, then the equations for the windowing transformation are

$$X_{vp} = \frac{1023}{2} \left(1 + \frac{X-WCX}{WS}\right) \quad, \tag{62}$$

and

$$Y_{vp} = \frac{1023}{2} \left(1 + \frac{Y-WCY}{WS}\right) \quad, \tag{63}$$

where the viewport is the entire face of the display screen. Also

involved in producing this effect is a process known as "clipping."

Clipping involves removing the lines outside of the region of interest

from the display. In Figure 43, all of the points in the coordinate

space undergo the transformations of equations (62) and (63). This

means that the display will try to produce lines outside of its

1024 x 1024 addressable space. On the 1559, this produces only a maze

of tangled lines crisscrossing the screen. The only way to display the

picture then is to remove those lines not actually within the specified

region of interest.

Figure 44 is a contour plot of the v-velocity component, and

Figure 45 is a plot of the u-velocity component. In Figure 46, we

have zoomed in slightly, and specified more contour levels, illustating

the capability of producing more detail when it is required. Figure

47 is a contour of the pressure field.
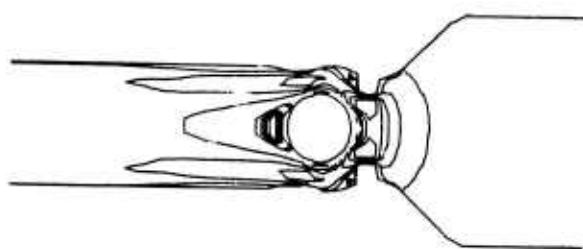
Figure 44

Contour Plot of V-Velocity
Component
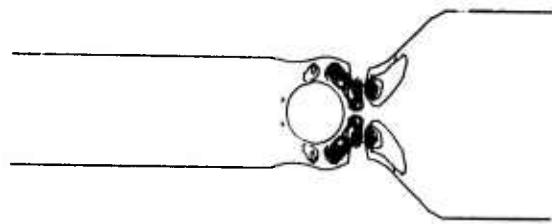
Figure 45

Contour Plot of U-Velocity
Component
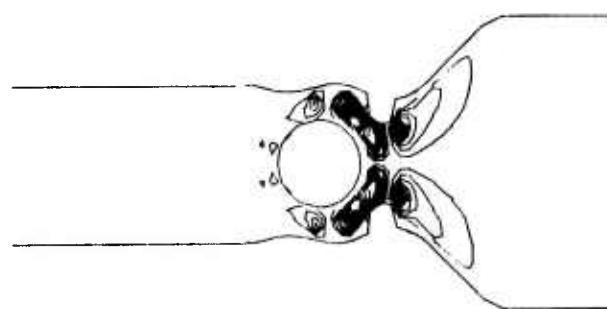
Figure 46

Contour Plot of U-Velocity Component
With More Contour Levels Specified
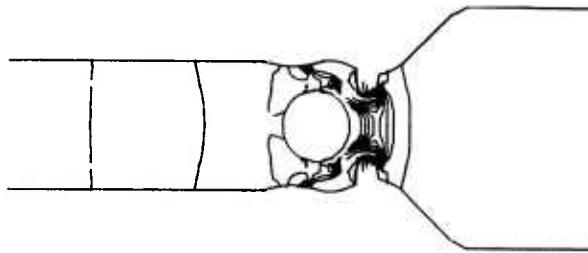
Figure 47

Contour Plot of Pressure

Velocity Vectors

Velocity vectors are produced by means of the subroutine VVECT.
This program blanks out areas where the velocity is too small to produce
a vector, so that some areas in the display will in fact appear blank.
Figures 48 and 49 are displays of velocity vectors.
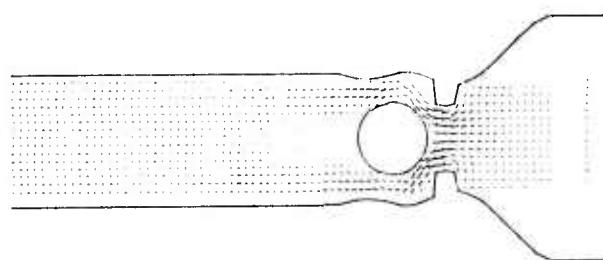
Figure 48

Computer Display of Velocity Vectors
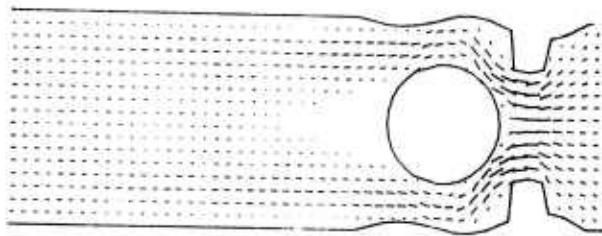
Figure 49

Same Display as Figure 48
With a Smaller Window

In the interactive graphics environment described in this chapter, the computer user can sit down at a conveniently placed graphics terminal. On the graphics display he can have his data presented in its natural form for both input and output. Decisions can be made at the display allowing several separate trials at a single session. Yet, this has been implemented with no appreciable load on the computer due to the addition of the interactive graphics.

CHAPTER SEVEN

RESULTS

A. NUMERICAL RESULTS

Several attempts were made in computing the flow about a ball type valve. The ABMAC technique as outlined in Chapter Four relies upon the assumption that a free-slip boundary condition exists at the arbitrarily shaped walls of the boundary and of the obstacle. As has been pointed out, in ABMAC these curved walls are treated as a free surface. In these surface cells, the pressure is computed according to the equation

$$P_{k,l}^{i+1} = P_{k,l}^{i} - \frac{\Delta \tau}{\delta} \{ [\ (V_p^{n+1})^i - V_b(r,t)] \cdot \hat{n} \}_{k,l} . \tag{64}$$

Here $\hat{n}$ is the unit normal defining the boundary segment associated with cell (k,l), $(V_b(r,t))_{k,l}$ is the velocity of the midpoint of the segment, and V_p^{n+1} is the liquid velocity at the midpoint of the segment. According to this equation, the pressure is not adjusted proportional to the divergence of the cell, but rather proportional to the flux across the boundary. This certainly represents a free-slip boundary condition. There can be no flow across the boundary wall, instead the fluid flow is forced to be tangential to the boundary.

The velocity vectors in Figure 50 illustrate this effect. Note that there are velocity vectors right on the surface of the ball. As a result of this, the velocity directly behind the ball does not drop off as expected. However, a strange side effect is shown in Figure 51.

In this display, note how the velocities far downstream react. They actually approach zero at the center of the tube.
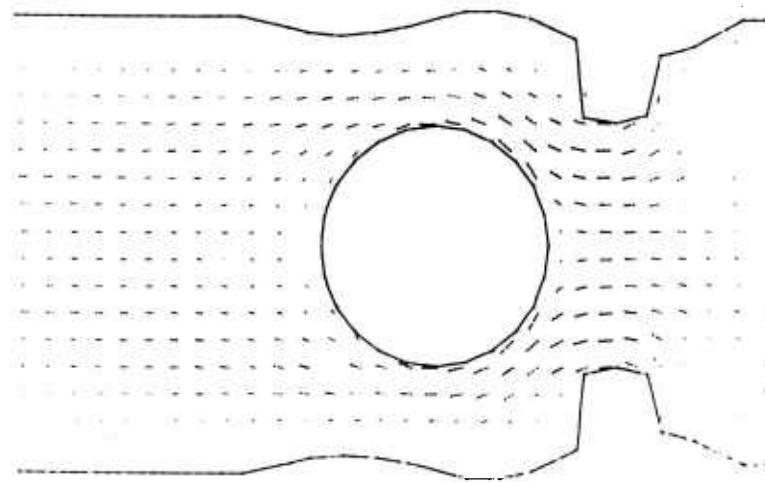
Figure 50

Computer Display of Velocity Vectors on
Ball with Free-Slip Boundary Condition
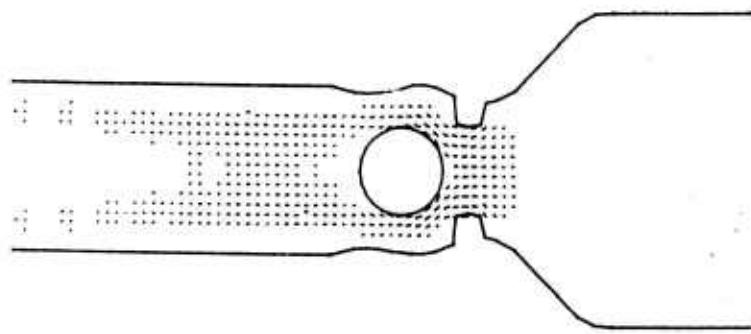
Figure 51

Computer Display of Downstream Anomoly
in Velocity Vectors with Free-Slip Boundary Condition

In order to pursue a more realistic solution, the case where the boundary is no-slip must be considered. By a no-slip boundary, we mean one on which both the normal and tangential velocity components are zero.

In the original MAC Technique, a no-slip boundary is specified as follows:

OUTSIDE   WALL   FLUID

$V_{j-1,j+1/2}$ $V_{i,j+1/2}$

$U_{i+1/2,j}$ ------ j

$U_{i-1/2,j}$

$V_{i-1,j-1/2}$ $V_{i,j-1/2}$

i-1   i
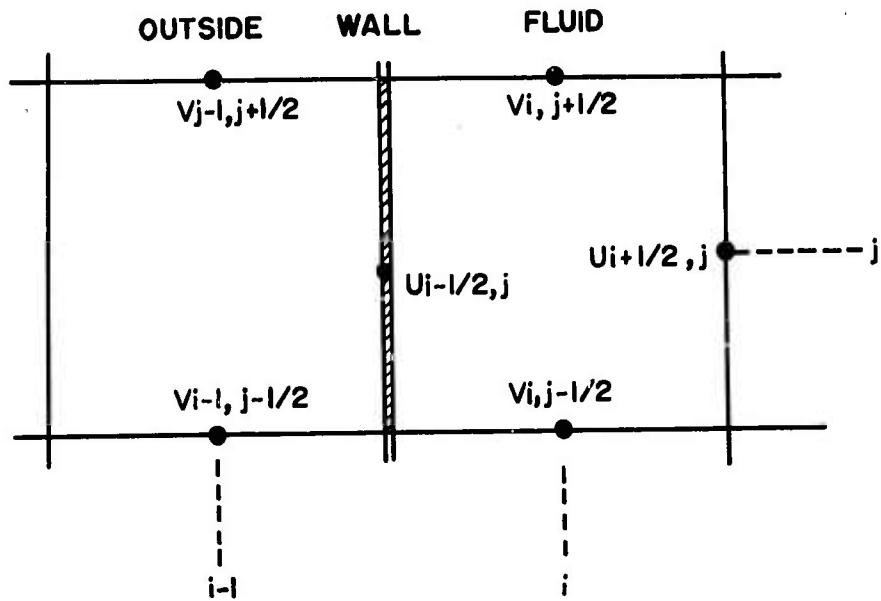
Figure 52

Specification of MAC No-Slip Boundary

$$U_{i-1/2,j} = 0 \tag{65}$$

$$V_{i-1,j+1/2} = -V_{i,j+1/2} \tag{66}$$

$$V_{i-1,j-1/2} = -V_{i,j-1/2} . \tag{67}$$

This scheme assumes that the wall is coincident with some part of the computing mesh. If, however, the wall is represented by an arbitrary

segment cutting through the cell, it should still be possible to
specify the across-the-wall velocities such that a no-slip boundary
condition exists.

There appear to be two classes of boundary configurations that
need to be considered. The first, represented in Figure 53, contains
those instances where there is an empty cell only on one side of the
cell containing the wall segment
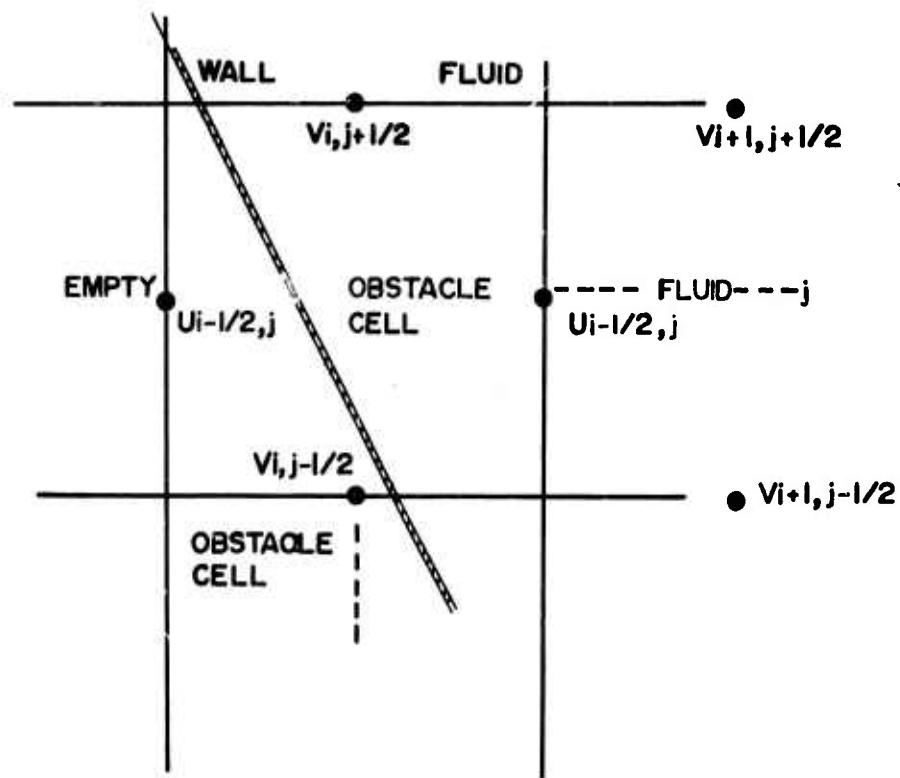
Figure 53

ABMAC Cell with Only One Empty Cell Bordering
the Cell Containing the Boundary Segment

In this class of cells, the velocities $V_{i,j+1/2}$, $V_{i,j-1/2}$, and
$U_{i-1/2,j}$ need to be computed such that a linear interpolation across
the boundary will yield zero velocity components on the wall. In
order to compute the required velocities, a linear interpolation is

used in the direction most nearly normal to the boundary segment. In Figure 54 the case under consideration is shown.
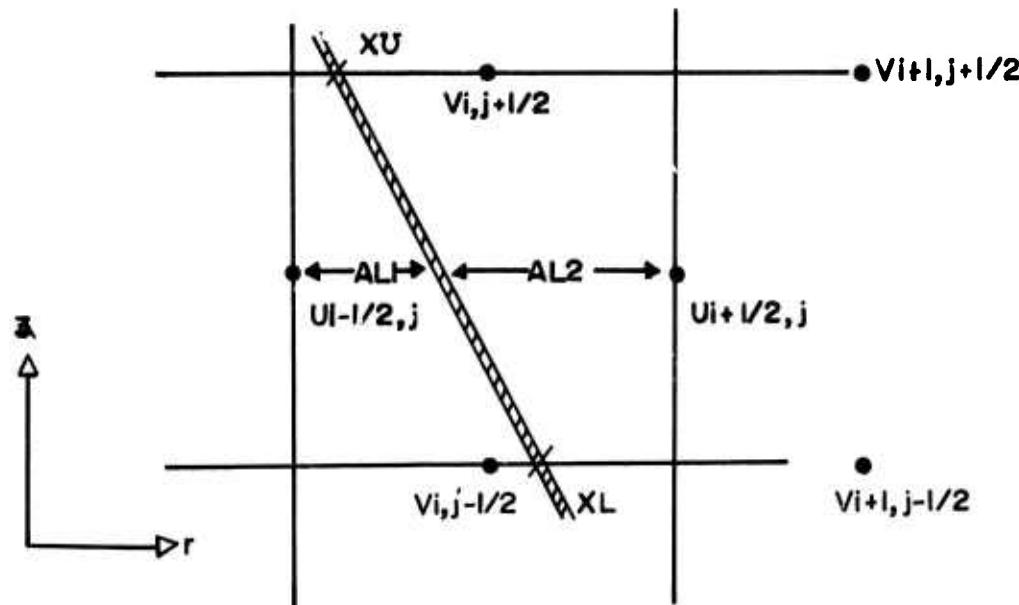
Figure 54

Linear Interpolation of Boundary Values for the
Class of Cells Illustrated in Figure 53.

Since the midpoint of the segment is known, for $U_{i-1/2,j}$

$$U_{i-1/2,j} = -(U_{i+1/2,j} * AL1) / AL2, \tag{68}$$

where AL1 and AL2 are easily computed.

In order to compute $V_{i,j-1/2}$, the point XL where the wall cuts the mesh must be known. Given PNORX and PNORY, the midpoint of the segment, and DNORX and DNORY, the direction cosines of the segment, the point XL is given by

$$XL = (Z_{j-1/2} - PNORY) / TAN + PNORX, \tag{69}$$

where

$$TAN = DNORX / DNORY. \tag{70}$$

Now with XL known, $V_{i,j-1/2}$ can be computed as in equation (68).
When the wall crosses the mesh outside of the unknown velocity as in
the case of $V_{i,j+1/2}$, it should be noted that equation (68) still
produces a correct velocity for that point.

This system works for all orientations of the boundary, where
only one side of the boundary cell faces an empty cell. The equations
for determining XU, XL, AL1, and AL2 are a little different for each
case, but the general approach is the same.

The second class of problems are those in which an empty cell
faces the obstacle cell on two sides. This is shown in Figure 55.
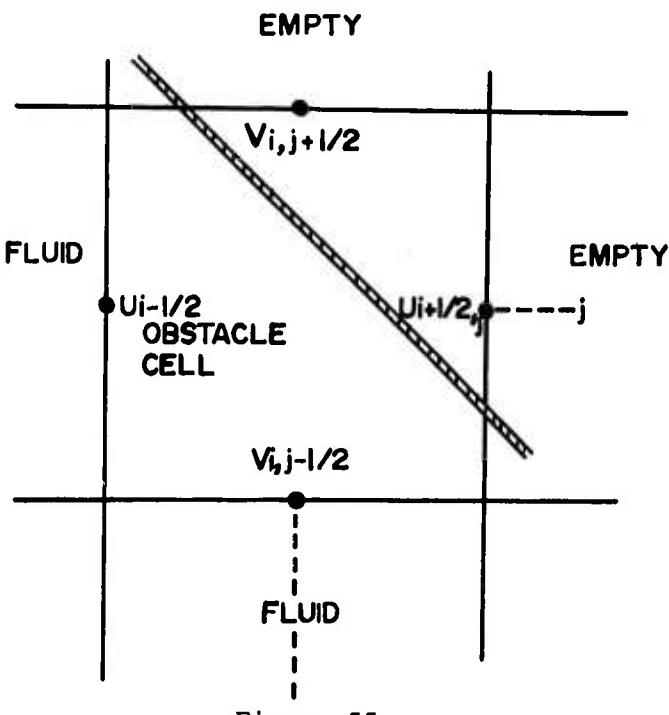
Figure 55

ABMAC Cell with Two Empty Cells Bordering the
Cell Containing the Boundary Segment

In this case, $V_{i,j+1/2}$ and $U_{i+1/2,j}$ will be computed using the
velocities directly across the cell. In order to do this, the lengths
XL, and YL must be known, as shown in Figure 56.
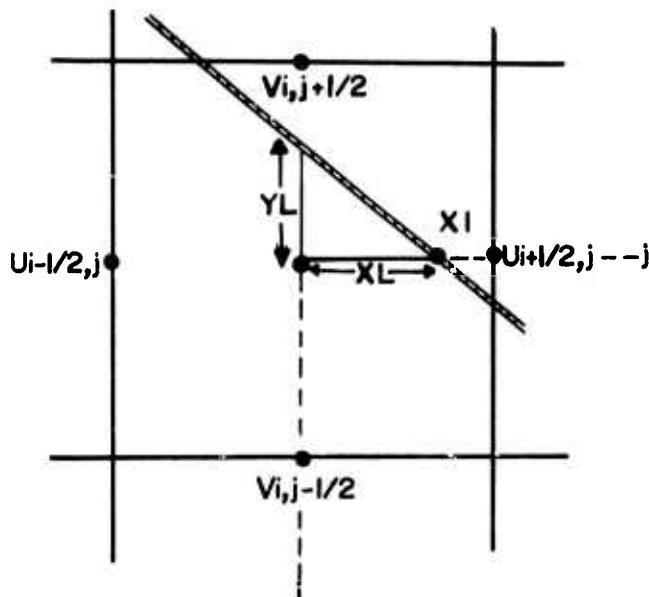
Figure 56

Computation of XL and YL for Determining the Boundary
Values for the Class of Cells Illustrated in Figure 55

Xl, the point where the boundary segment crosses the line $z = z_i$

is given as

$$Xl = (Z_j - PNORY) \,/\, TAN + PNORX, \tag{71}$$

where PNORY, PNORX, and TAN have identical meanings as in equation (69).

With Xl known, the lengths XL and YL can be computed and the velocities

found using a linear interpolation formula.

Results using the no-slip boundary condition represent a far

better solution than those with the free slip condition. The velocity

profiles shown in Figures 57 and 58 are at positions upstream from the

ball. Those in Figures 59, 60, and 61 are at positions downstream from

the ball. These profiles represent a realistic simulation of the flow

about a ball type valve.
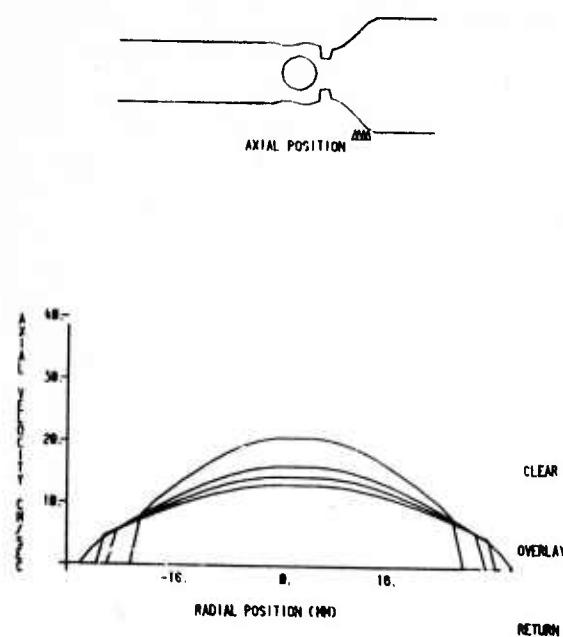
Figure 57

Figure 58

Upstream Velocity Profiles
For No-Slip Boundary Condition
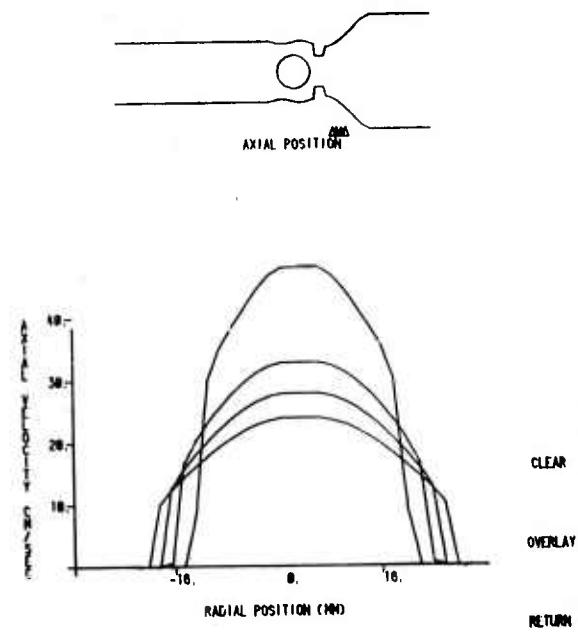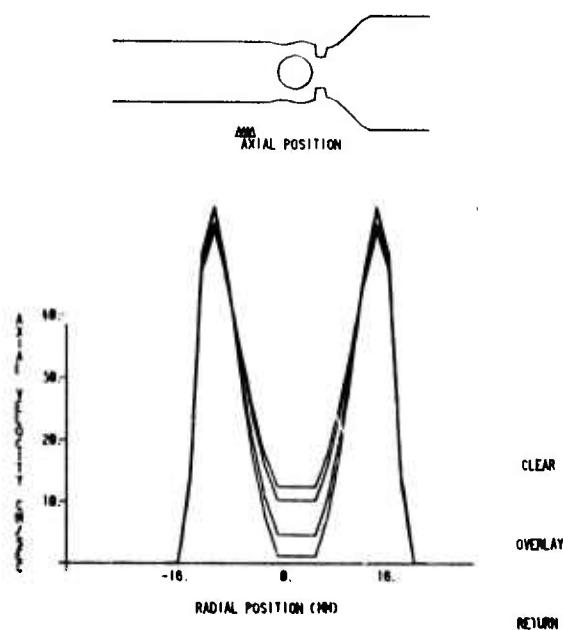
Figure 59

Figure 60

Downstream Velocity Profiles
for No-Slip Boundary Conditions
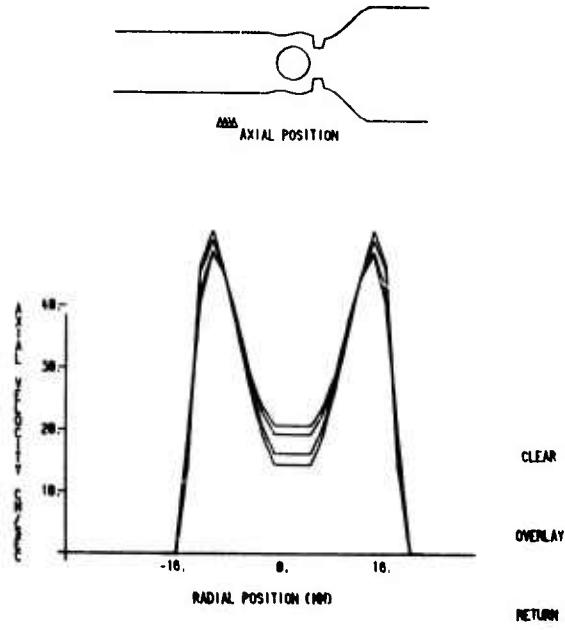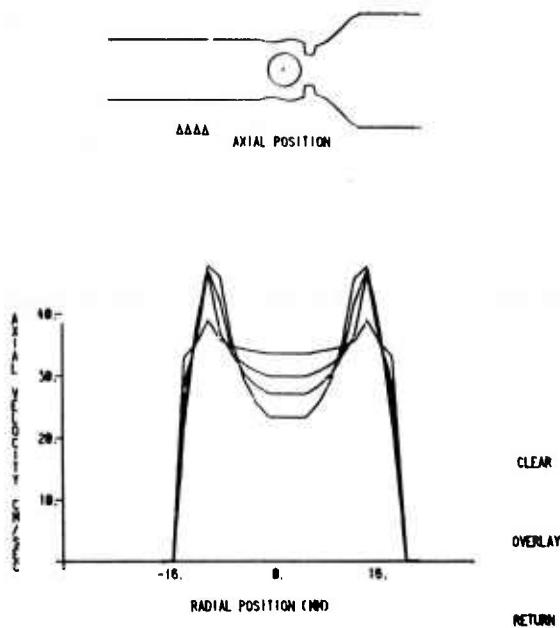
Figure 61

Downstream Velocity Profiles
for No-Slip Boundary Conditions

Figure 62 and 63 are comparisons of these velocity profiles with

selected profiles produced experimentally by Wieting. The shapes of

the profiles are very similar, but note that those produced numerically

show slightly faster velocities.

The differences can be attributed to several factors. First, the

numerical solution represented here is a steady state solution, i.e.

given some initial conditions and a set of boundary conditions, the

computer iterates on the given equations until the solution satisfies

the given conditions. The experimental solution on the other hand is

time dependent. The pulsatile motion of the fluid, the motion of the

ball, and other time dependent factors will certainly make a difference.

The exact moment at which the profiles were measured could in itself
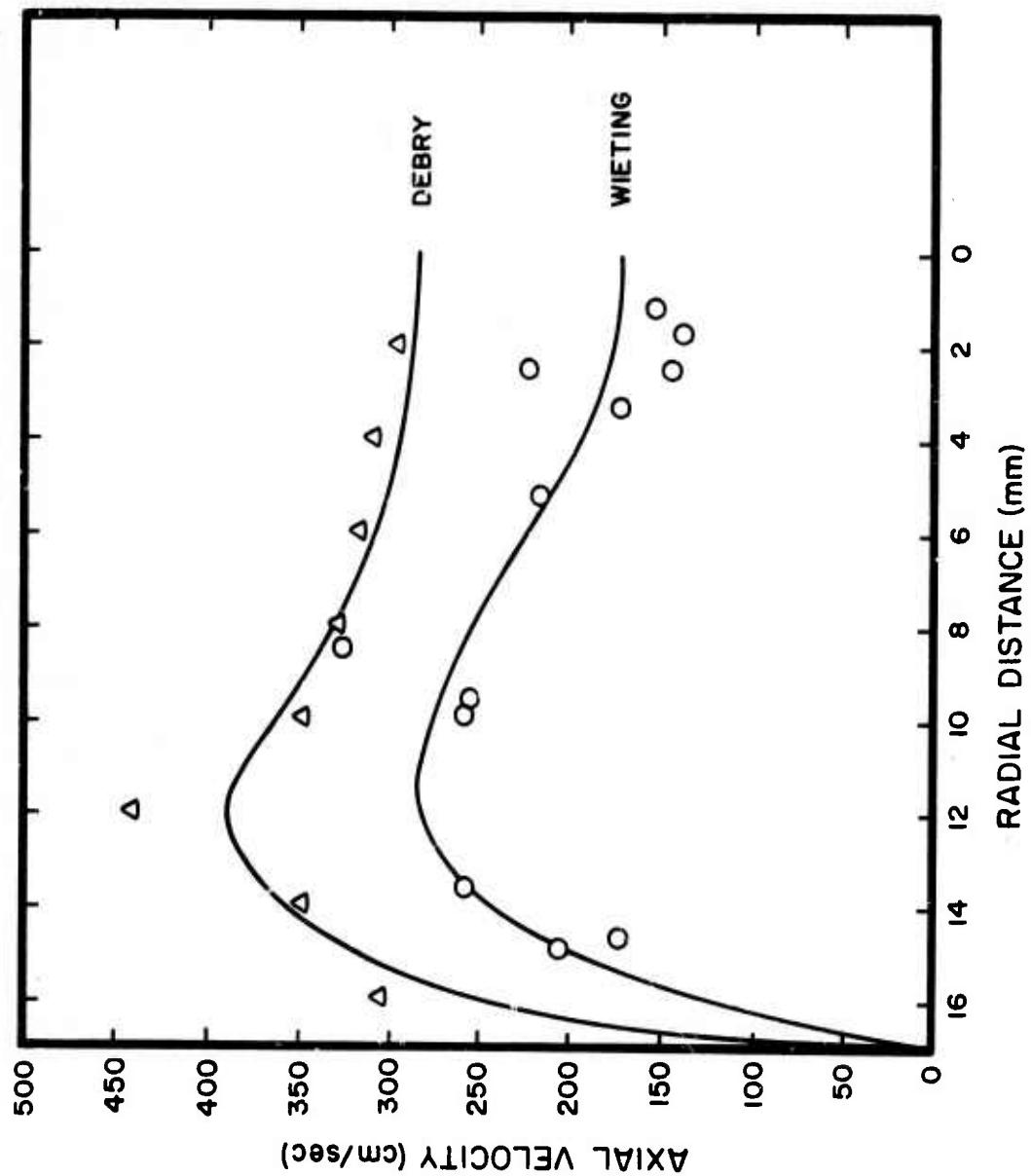
Figure 62
Comparison of Calculated Velocity Profiles with Experimental
Data (Wieting), at position z = 79mm., downstream of sewing
ring position.

Figure 63
Comparison of Calculated Velocity Profiles with Experimental
Data (Wieting), at position z = 68mm., downstream of sewing
ring position.
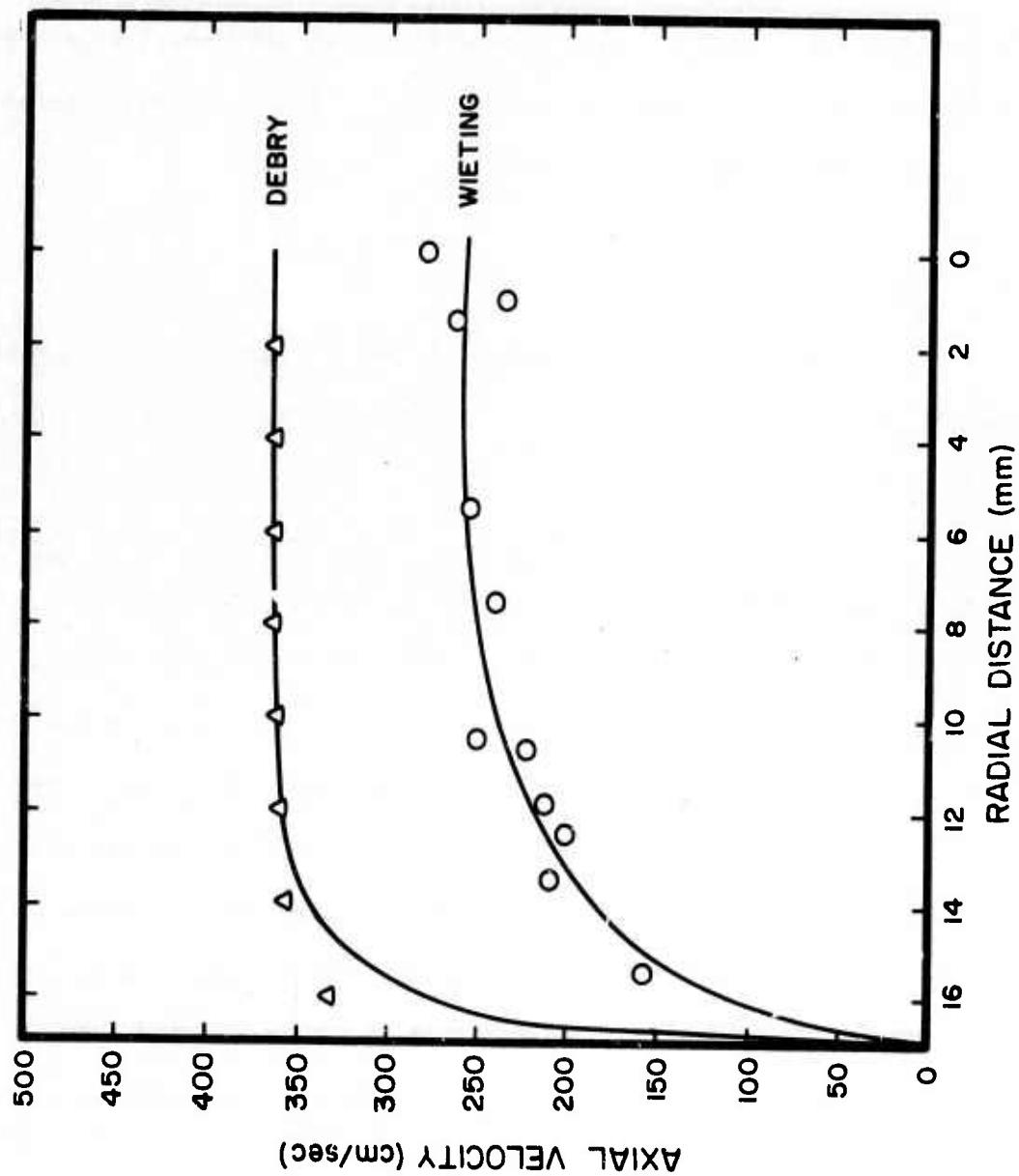
produce different results. From a numerical standpoint, a more accurate solution could certainly be obtained if a finer computational mesh were used.

Figures 64, 65, 66, and 67 are contour plots of the stream-function, V-velocity component, U-velocity component, and pressure. Figure 68 shows the velocity vectors for the solution. These figures represent a realistic representation of the flow.

B. THE COMPUTER PROGRAM

In addition to producing numerical results, the goal of this research was to produce a series of programs which used the computer to its best advantage.

In order to make the ABMAC code more efficient for use on the PDP-10 time sharing system, several changes were made in the program.

The first major change involved separating the initialization portion of the program from the computational part. This is a significant change for many reasons. During the initialization procedure, the curved boundary segments are defined, fluid particles are created, and the cell flags are marked. This involves a great deal of time, program space, and temporary storage. By separating this code from the rest of the program, the amount of core required to run in dropped from 96K to 48K. Under our time sharing system, this means a considerable increase in efficiency.

During a long production run, the set-up time may be insignificant when compared to the total run time. However, testing and debugging pose an entirely different picture. Usually, interest lies only in the
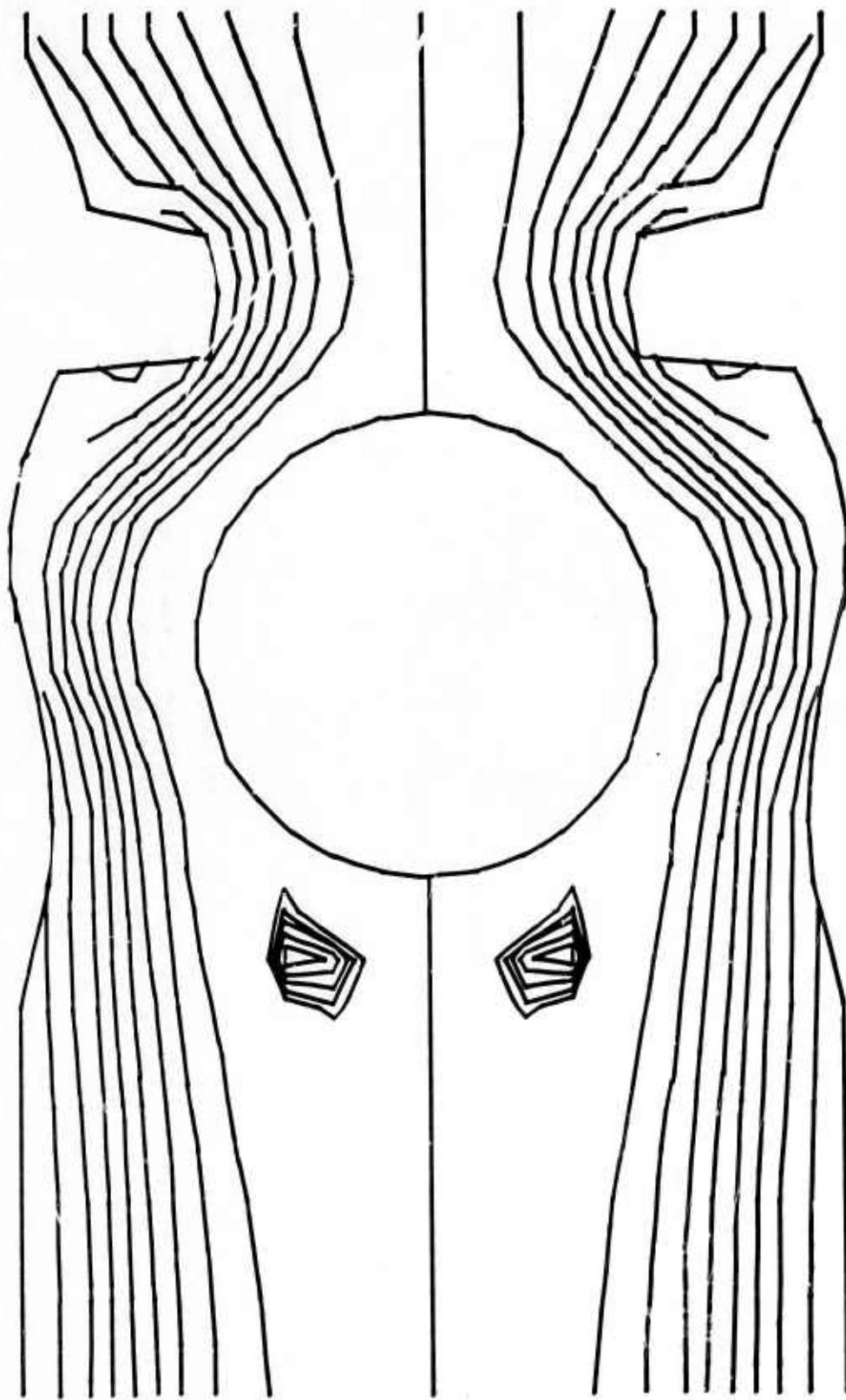
Figure 64

Computer Display of the Contour Plot of the Stream Function
for No-Slip Boundary Solution of Blood Flow About
a Starr-Edwards Ball Type Valve
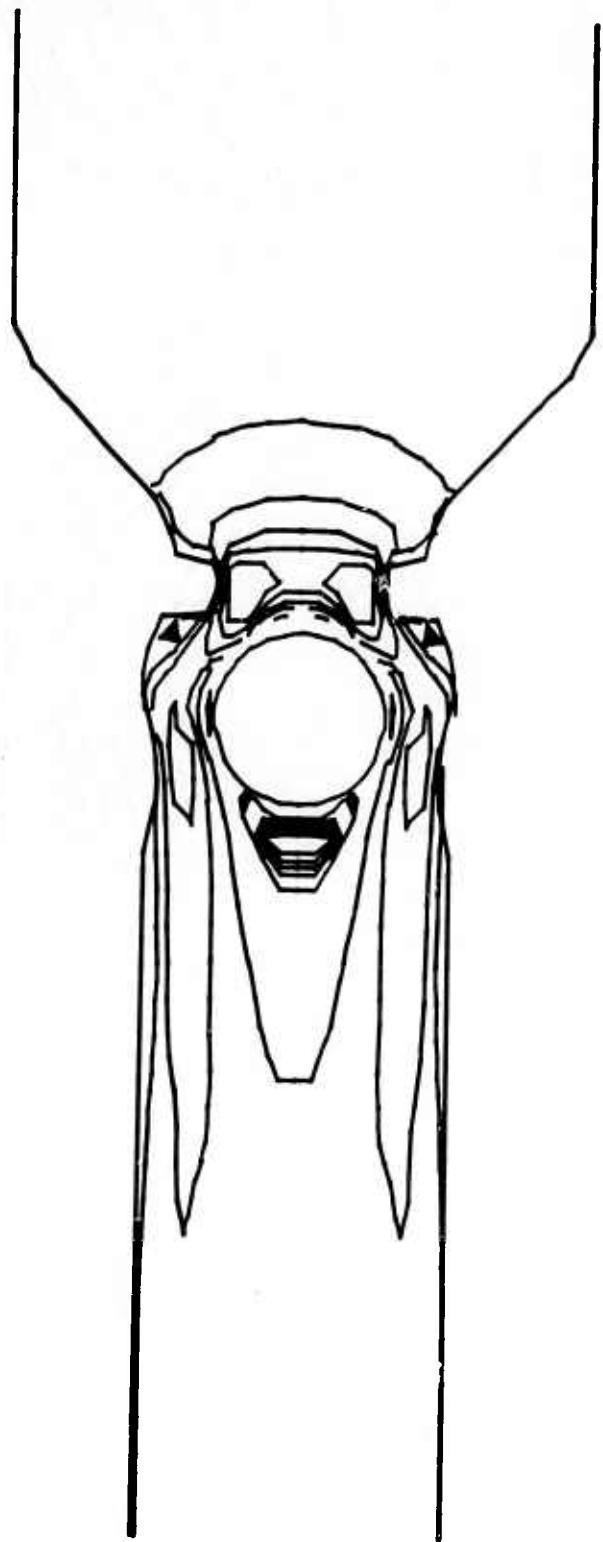
Figure 65

Computer Display of the Contour Plot of the V-Velocity Component
for No-Slip Boundary Solution of Blood Flow About
a Starr-Edwards Ball-Type Valve
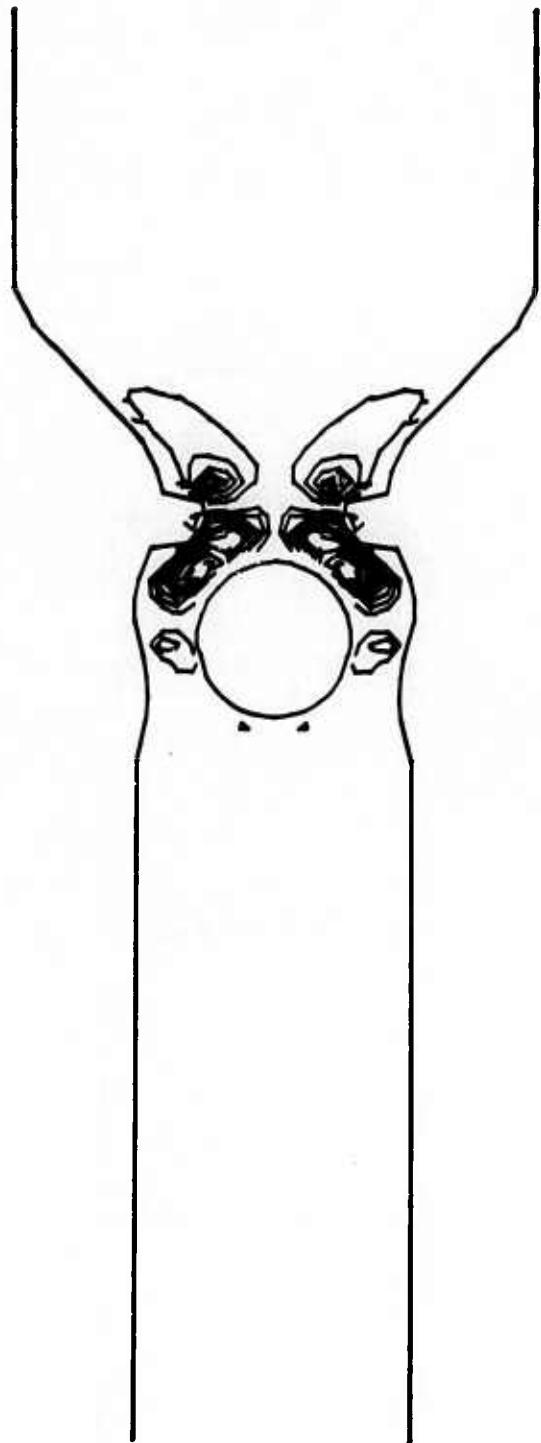
Figure 66

Computer Display of the Contour Plot of the U-Velocity Component
for No-Slip Boundary Solution of Blood Flow About
a Starr-Edwards Ball-Type Valve
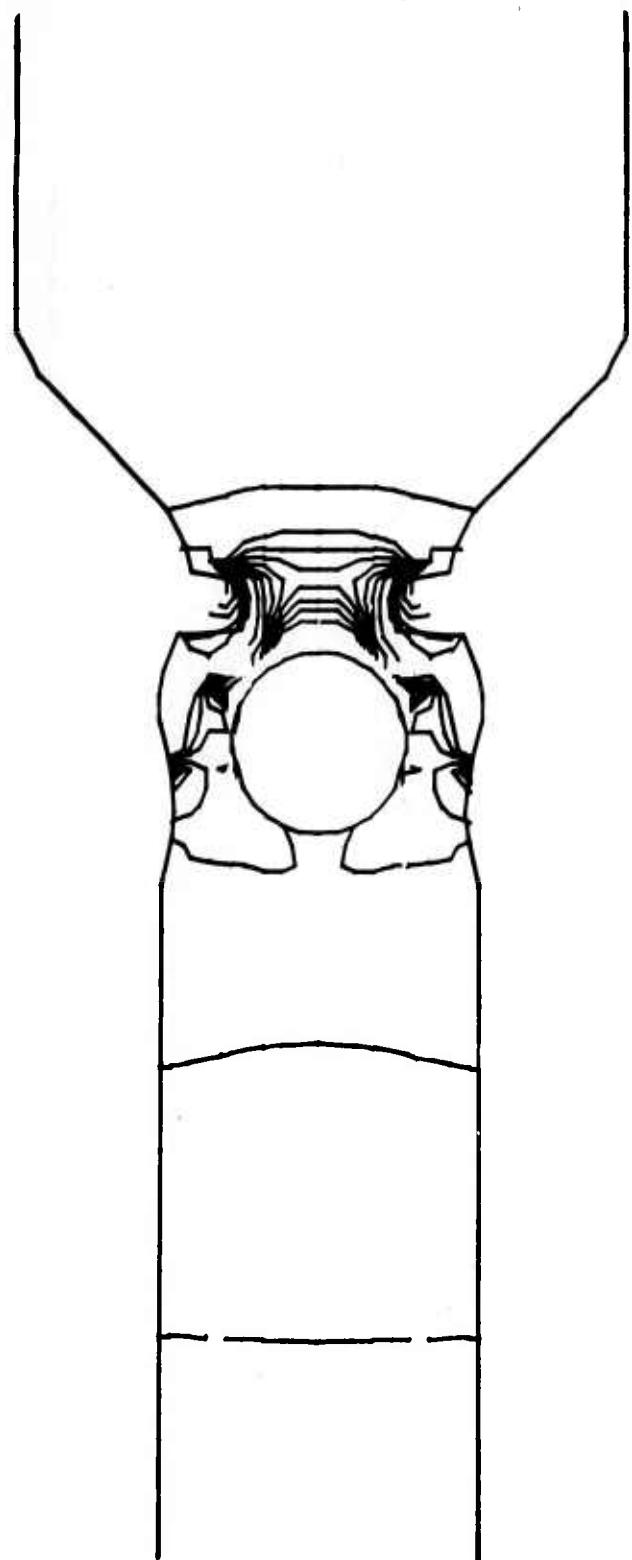
Figure 67

Computer Display of the Contour Plot of the Pressure Field
for No-Slip Boundary Solution of Blood Flow About a
Starr-Edwards Ball-Type Valve
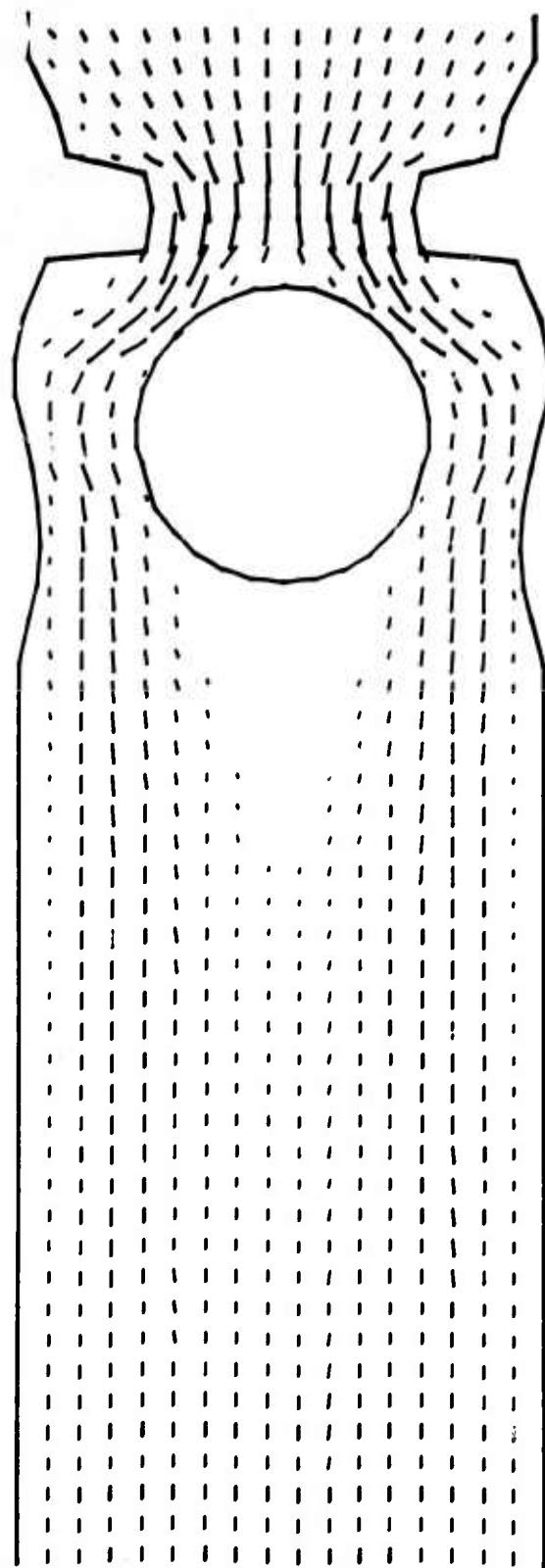
Figure 68

Computer Display of Velocity Vectors for No-Slip Boundary
Solution to Blood Flow About a
Starr-Edwards Ball-Type Valve

first one or two time cycles. In this frame of reference, the set up
time becomes a large part of the total run time. Therefore, by removing
that code from the rest of the program, the set-up for a particular
test need only be done once. Each test can use the same stored values
of initial data. The overall scheme of the initialization procedure is
shown in Figure 69.

```
┌─────────────────────┐
│   READ IN INITIAL   │
│       DATA          │
└─────────────────────┘
          │
          ▼
┌─────────────────────────┐
│ DEFINE CURVED BOUNDARY  │
│ SEGMENTS, CREATE FLUID  │
│ PARTICLES, MARK CELL    │
│ FLAGS, AND SET UP INITIAL│
│ VALUES OF VARIABLES.    │
└─────────────────────────┘
          │
          ▼
┌─────────────────────┐
│  WRITE OUT INITIAL  │
│   DATA TO FILE.     │
└─────────────────────┘
```
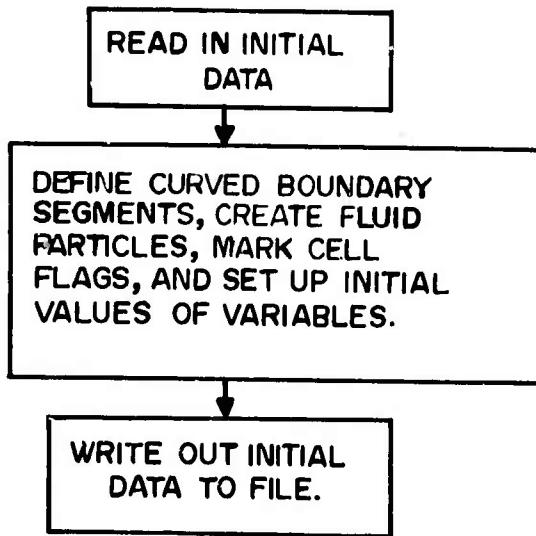
Figure 69

Block Diagram of Initialization Procedure
For Modified Version of ABMAC Code

The second change involved combining several pieces of code into
common subroutines. The major changes in this respect involved the
velocity computation code. The ABMAC technique requires a velocity
computation at two distinct times. As the pressure is re-computed for
each cell, the velocities are simultaneously changed for that cell. In
addition, at the end of each pressure iteration, the entire field of

velocities is re-computed. Although computationally the same, the codes

for these two distinct subroutines are different.

It was a simple matter, to combine these subroutines, using a check

to determine which function to perform. Subroutine VEL55 for example is

called with three arguments. If one of these arguments is zero, it

indicates that the entire mesh is to be swept. If non zero, the arguments

indicate which cell the velocities are to be computed in. The code to

do this is as follows:

```
      SUBROUTINE VEL55 (KM, K, L)
      COMMON STATEMENTS
      .
      .
      .
      IF (KM, NE . 0) GO TO 10
      DO 1 L = 2, LMZ
      KMM = L  KMAX
      DO 1 k = 2, KMZ
      KM = K + KMM - KMAX
   10 KT = KM + KMAX
      KB = KM - KMAX
```

The third change involved the determination of a system for setting

and checking cell flags. The original ABMAC code, written in LRLTRAN

for the CDC 7600, took advantage of several nice language features not

generally available. In particular, LRLTRAN contains a byte specification

and a structure specification. In ABMAC, the cell glags SUR, FULL, EMP,

BND, and etc., were specified as 1 bit bytes. These flags were then

combined into one word using the structure specification, and that set

of flags was made into an array.

These 1 bit bytes could then be accessed by name. For example:

OB (KM) = 1,

FULL (KM + 1) = 0 .

Treating these quantities as truth values made it easy to check
cell flags and make decisions based on their contents. For example:

```
TEST = FULL (KM). UN. (SUR (KM) . INT. (.NOT.COR(KM)))
IF (TEST) 20, 192.
```

In this illustration, are shown three other items peculiar only to
LRLTRAN. .UN. is a bit or, .INT. is a bit by bit AND, and the statement

```
IF (TEST) 20, 192
```

means go to statement 20 if test is true, and go to statement 192 if it
is false.

In order to simulate this scheme as efficiently as possible, a
table was devised which marked the cells as powers of two. The flags
are defined as

```
   SUR =      4
  FULL =      8
   EMP =     16
   BND =     32
    IN =     64
   OUT =    128
 FRSLP =    256
 NOSLP =    512
EMPBND =   1024
    OB =   2048
   COR =   4096
    OK =   8192
   GAS =  16384
   ARB =  32768
```

A cell then can be marked as full by writing

```
FLAG (KM) = LFAG (KM) . OR. FULL,
```

while checking the cell to see if it is full can be done by writing

```
IF ((FLAG(KM), AND.FULL).EQ.FULL) ...  .
```

It can be seen that while it takes more source code to write the same

thing, the code for the PDP-10 is just as efficient both space-wise and time-wise.

The final major change was one dictated by the heavy load this type of problem placed on the system. Since the problem is being run on a time-shared system, it must compete in time with other jobs. The scheduler on the PDP-10 is such that a long compute bound job is not favored. In order to take advantage of all possible time available on the machine, and yet not load the system, the following scheme was used.

The PDP-10 allows background jobs to be initiated using a system program called FIB. FIB queues up requests for background jobs, and runs them whenever the machine load average drops below a specified point. Jobs are run according to the requested run times, i.e., a job requesting two minutes of CPU time will run before one requesting four minutes. If a process can be broken up into discreet segments, such that each segment uses two minutes or less, the FIB program will use all available machine time to run these segments without loading the machine.

ABMAC runs through one time cycle in about 12 minutes. This provides a convenient place to segment the process. Instead of writing out a file at the end of each segment, and reading it in at the beginning of the next, the program maps a complete core image of itself onto a file called P.DMP. At the beginning of the next cycle the command RUN P.DMP is sufficient to start the next cycle with all of the proper data.

In the event that the machine crashes during this mapping operation, two different versions of P.DMP are written out, the program alternating

between them. This insures that there is always one complete, good version of P.DMP. on the system.

In order to keep the program running, the FIB request must generate the next FIB request as well as the next program segment. Also, it must be sure that it uses the correct version of P.DMP. The FIB request necessary to do this is shown here. The machine responses are underlined.

```
(1)        @ FIB
(2)        @@ <SYSTEM> EXEC. SAV
(3)        @@ CONSOLE-OUTPUT (TO FILE)  NIL.DAT  [NEW FILE]
(4)        @@ RUNTIME (MAXIMUM IN MINUTES)  2  [CONFIRM]
(5)        @@ COMMAND-TEXT (ENDING WITH ↑ Z)
(6)        * COPY O-REQUEST.INPUT (TO) REQUESTED-F-I-B. INPUT
(7)        * RUN GETIT
(8)        * P
(9)        * Y
(10)       * Y
(11)       * N
(12)       * ↑ Z
(13)       @
```

Line (1) calls up the FIB program. Line (2) tells FIB that it is to run the system EXEC routine. Line (3) specifies that any console output is to go to a file named NIL.DAT. Line (4) specifies a two minute maximum run time. Line (5) asks for a list of commands and/or text to be executed by the routine specified in line (2). Line (6) copies from a file O-REQUEST.INPUT, the next FIB request. This is put into the queue by writing it onto a file called REQUESTED-F-I-B.INPUT. Line (7) tells the system to run a program called GETIT. GETIT looks at the version numbers of P.DMP, selects the proper one, and maps it

onto core. Control is then passed to P.DMP. Lines (8), (9), (10), and (11) contain text which is used by P.DMP. Line (12) terminates the list, and line (13) returns to the EXEC.

CHAPTER EIGHT

CONCLUSIONS

The numerical results of this study illustrate the applicability
of a unique numerical technique to an extremely important problem. The
development of a method for specifying a flexible, arbitrarily shaped,
no-slip boundary provides an important step in studying blood flow
characteristics. The technique developed in this report is based on
the Marker and Cell methodology produced at Los Alamos Scientific
Laboratory. This method, using marker particles, provided a powerful
method for defining free surfaces in a fluid flow study, as well as the
ability to solve the problem in terms of the primitive variables of
velocity and pressure. The marker particle concept allowed the
definition of an arbitrarily shaped, flexible boundary in the flow
problem, as demonstrated in the ABMAC method developed at the Lawrence
Livermore Labs. Adding the no-slip boundary concept developed in this
report to ABMAC provides a powerful tool for blood flow studies.

It should be noted that in the steady-state, confined flow
solutions presented in this paper, the marker particles used originally
in MAC have no significance, and in fact have been eliminated from the
computation altogether. Therefore, no figures containing marker particles
appear in the text. However, once the walls are allowed to flex, or the
ball is allowed to move, the particles again become important in
maintaining the definition of the walls.

In addition to the development and application of a new numerical
method, this report has illustrated the kinds of techniques necessary

in order to include an interactive graphic capability in the solution.
Interactive computer graphics can play an important role in the solutions
of large numerical problems, but the implementation of such a capability
must be done with care. Performed in the wrong manner, it can hinder
the solution process rather than help it. The techniques of program
segmentation and modularization along with core sharing provide an
efficient, powerful implementation of interactive graphics.

The next logical step in this research would be to add the moving
boundary capability. Basically, this is simply a matter of re-introducing
the marker particles into the solution in order to keep track of the
moving boundaries. Some programming would also need to be included to
define the movement that would be desired in the walls. For example,
the ball would be moved as a function of the pressure field, the walls
could move according to a pulsatile waveform superimposed on the system.

The addition of this feature would allow a motion-picture type of
display, where the streamlines, velocities, etc. could be seen changing
as the valve went through an open-close cycle. With this kind of tool,
a capability would be available for studying many different heart
valve designs. With the information gained from that kind of study,
new heart valves can be designed and evaluated with the computer.

This technology will be extended into other blood flow studies,
such as capillary flow, the formation of atherosclerotic plaques, and
pulmonary functions.

Of particular interest to the study of plaque or lesion formation
in arteries is the allowance of apulsing, arterial wall and blood flow
into the overall investigation by this procedure. For example, the

prime cause of some 800,000 heart attacks in the United States each

year is an infarction of a coronary artery. Such an obstruction of

the local circulation by an advanced plaque formation, thrombus or

embolus is involved in a many-branched amplification of our present

studies concerning arterial geometrics. It is realized that the inclusion

of moving (pulsing), free boundaries and their computer graphics

simulations into the problem will allow tethering, tapering and reflection

effects; conceptual requirements that would aid in advancing the hypotheses

of myocardial infarction mechanisms. Knowledge of such mechanisms may

not be attainable by any other analytical means except by such resulting

computer simulations.

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APPENDIX I

GRAPHICAL INPUT PROGRAM

Routine Name	Function
MAIN	Main program
MAIN1	Displays input selection
INPUT	Controls input
INPUT1	Displays input functions
MESH	Controls mesh input
MESH1	Accepts mesh input
MESH2	Displays mesh input
FIGURE	Controls figure input
FIG1	Displays input functions
FIG2	Displays mesh
FIG3	Accept figure input
FIG4	Displays figure
TTYIN	Does teletype input
FLUID	Controls fluid input
FLU1	Accepts fluid input
FLU2	Displays fluid input
CONVG	Controls parameter input
CONVG1	Accepts parameter input
CONVG2	Displays parameter input
CNTRL	Controls parameter input
CNTRL1	Accepts parameter input
CNTRL2	Displays parameter input
CHECK	Displays completed description
OUTP	Outputs completed description
ARO	Draws arrow heads
BOXES	Draws light buttons
BOX	Draws one box

```
      COMMON MESS(7)
      COMMON KMAX,LMAX,MU,RHOA,DR,DZ
      COMMON NP,BPX(50),BPY(50),UNOT,VNOT,UIN,VIN
      COMMON DT,NEDIT,EPS2,BETA,NSTOP,NPIT,NDUMP,NEXP
      COMMON/MOUSE/INX,INY,INSW,SWSTAT
      COMMON/ETC/ISMX1,ISMX2,NXSP,NYSP,FNAME
      INTEGER FNAME
      REAL MU
      CALL SETDIS
      CALL MAIN1
      CALL WMOUSE
      INY=(INY+128)/128
      GO TO (5,2,1)INY
C
C     JUMP TABLE FOR INPUT TYPE
C     1-TTY
C     2-DISK
C     3-TERMINAL
C
1     NDEV1=5
      CALL READIT
      CALL EXIT
2     NDEV1=21
      TYPE 3
3     FORMAT(1H ,'INPUT FILENAME:',$)
      ACCEPT 4,FNAME
4     FORMAT(A5)
      FNAME=FNAME+32
      CALL IFILE(21,FNAME)
      CALL READIT
      CALL EXIT
5     NDEV1=0
      CALL INPUT
      CALL EXIT
      END
```

```
SUBROUTINE MAIN1
CALL BOXES(3)
CALL MOVETO(752,24)
CALL WRITE('TERMINAL<>')
CALL MOVETO(768,152)
CALL WRITE('DISK<>')
CALL MOVETO(768,280)
CALL WRITE('TTY<>')
CALL MOVETO(728,350)
CALL WRITE('INPUT FROM:<>')
CALL SEND
RETURN
END
```

```
        SUBROUTINE INPUT
        COMMON/MOUSE/INX,INY,INSW,SWSTAT
1       CALL INPUT1
        CALL WMOUSE
        INY=(INY+128)/128
        GO TO (2,3,4,5,6,7,8)INY
C
C       JUMP TABLE FOR INPUT MODULES
C
2       CALL CHECK
        CALL WMOUSE
        CALL OUTP
        CALL EXIT
3       CALL MOD
        GO TO 1
4       CALL CNTRL
        GO TO 1
5       CALL CONVG
        GO TO 1
6       CALL FLUID
        GO TO 1
7       CALL FIGURE
        GO TO 1
8       CALL MESH
        GO TO 1
        END
```

```
SUBROUTINE INPUT1
CALL BOXES(7)
CALL MOVETO(768,24)
CALL WRITE('EXIT<>')
CALL MOVETO(750,152)
CALL WRITE('MODIFY<>')
CALL MOVETO(740,280)
CALL WRITE('CONTROL<>')
CALL MOVETO(732,422)
CALL WRITE('CONVERGENCE<>')
CALL MOVETO(748,390)
CALL WRITE('CRITERIA<>')
CALL MOVETO(760,536)
CALL WRITE('FLUID<>')
CALL MOVETO(746,664)
CALL WRITE('BOUNDARY<>')
CALL MOVETO(768,792)
CALL WRITE('MESH<>')
CALL SEND
RETURN
END
```

```
        SUBROUTINE MESH
        COMMON/MOUSE/INX,INY,INSW,SWSTAT
        DO 1 I=1,5
1       CALL MESH1(I)
2       CALL WMOUSE
        INY=(INY+128)/128
        IF(INY.GE.6) GO TO 3
        CALL MESH1(INY)
        GO TO 2
3       CONTINUE
        RETURN
        END
```

```
      SUBROUTINE MESH1(J)
      COMMON MESS(7)
      COMMON KMAX,LMAX,MU,RHOA,DR,DZ
      COMMON NP,BPX(50),BPY(50),UNOT,VNOT,UIN,VIN
      COMMON DT,NEDIT,EPS2,BETA,NSTOP,NPIT,NDUMP,NEXP
      COMMON/MOUSE/INX,INY,INSW,SWSTAT
      COMMON/ETC/ISMX1,ISMX2,NXSP,NYSP
      GO TO (4,6,8,13,15)J
4     TYPE 5
5     FORMAT(1H ,'DR=',$)
      ACCEPT 3,DR
2     FORMAT(A1)
3     FORMAT(F)
      GO TO 18
6     TYPE 7
7     FORMAT(1H ,'DZ=',$)
      ACCEPT 3,DZ
      GO TO 18
8     TYPE 9
9     FORMAT(1H ,'RECT OR CYL COORD?',$)
      ACCEPT 2,NSYS
      IF(NSYS.EQ.'R')NEXP=0
      IF(NSYS.EQ.'C')NEXP=1
      GO TO 18
13    TYPE 14
14    FORMAT(1H ,'NO. OF CELLS IN R=',$)
      ACCEPT 12,KMAX
      GO TO 18
15    TYPE 16
16    FORMAT(1H ,'NO. OF CELLS IN Z=',$)
      ACCEPT 12,LMAX
      NYSP=800/(LMAX-2)
      NXSP=NYSP*DR/DZ
12    FORMAT(I)
18    CALL MESH2
      RETURN
      END
```

```
SUBROUTINE MESH2
COMMON MESS(7)
COMMON KMAX,LMAX,MU,RHOA,DR,DZ
COMMON NP,BPX(50),BPY(50),UNOT,VNOT,UIN,VIN
COMMON DT,NEDIT,EPS2,BETA,NSTOP,NPIT,NDUMP,NEXP
COMMON/MOUSE/INX,INY,INSW,SWSTAT
COMMON/ETC/ISMX1,ISMX2,NXSP,NYSP
CALL BOXES(6)
CALL MOVETO(744,24)
CALL WRITE('DR=Δ.ΔΔΔΔ<>',DR)
CALL MOVETO(744,152)
CALL WRITE('DZ=Δ.ΔΔΔΔ<>',DZ)
CALL MOVETO(746,280)
IF(NEXP.EQ.0)CALL WRITE('RECT COORD<>')
IF(NEXP.EQ.1)CALL WRITE('CYL COORD<>')
CALL MOVETO(722,422)
CALL WRITE('NO. OF CELLS<>')
CALL MOVETO(734,390)
CALL WRITE('IN R=ΔΔΔ<>',KMAX)
CALL MOVETO(722,550)
CALL WRITE('NO. OF CELLS<>')
CALL MOVETO(734,518)
CALL WRITE('IN Z =ΔΔΔ<>',LMAX)
CALL MOVETO(768,664)
CALL WRITE('RETURN<>')
CALL SEND
RETURN
END
```

```
      SUBROUTINE FIGURE
      COMMON MESS(7)
      COMMON KMAX,LMAX,MU,RHOA,DR,DZ
      COMMON NP,BPX(50),BPY(50),UNOT,VNOT,UIN,VIN
      COMMON DT,NEDIT,EPS2,BETA,NSTOP,NPIT,NDUMP,NEXP
      COMMON/MOUSE/INX,INY,INSW,SWSTAT
      COMMON/ETC/ISMX1,ISMX2,NXSP,NYSP
      CALL FIG1
10    CALL WMOUSE
      INY=(INY+128)/128
      GO TO (1,2,7)INY
1     RETURN
2     TYPE 3
3     FORMAT(1H ,'INFLOW VELOCITIES:')
      TYPE 4
4     FORMAT(1H ,'V-IN=',$)
      ACCEPT 5,VIN
5     FORMAT(F)
      TYPE 6
6     FORMAT(1H ,'U-IN=',$)
      ACCEPT 5,UIN
      GO TO 10
7     CALL FIG2
      CALL FIG3
      GO TO 10
      RETURN
      END
```

```
SUBROUTINE FIG1
CALL BOXES(3)
CALL MOVETO(768,24)
CALL WRITE('RETURN<>')
CALL MOVETO(740,152)
CALL WRITE('INFLOW<>')
CALL MOVETO(732,280)
CALL WRITE('BOUNDARIES<>')
CALL SEND
RETURN
END
```

```
SUBROUTINE FIG2
COMMON MESS(7)
COMMON KMAX,LMAX,MU,RHOA,DR,DZ
COMMON NP,BPX(50),BPY(50),UNOT,VNOT,UIN,VIN
COMMON DT,NEDIT,EPS2,BETA,NSTOP,NPIT,NDUMP,NEXP
COMMON/MOUSE/INX,INY,INSW,SWSTAT
COMMON/ETC/ISMX1,ISMX2,NXSP,NYSP
KMAXZ=KMAX-2
LMAXZ=LMAX-2
MAXY=LMAXZ*NYSP+128
MAXX=KMAXZ*NXSP+128
DO 10 I=1,KMAX-1
NXLINE=128+(I-1)*NXSP
CALL MOVETO(NXLINE,128)
10    CALL VECTO(NXLINE,MAXY)
DO 20 J=1,LMAX-1
NYLINE=128+(J-1)*NYSP
CALL MOVETO(128,NYLINE)
20    CALL VECTO(MAXX,NYLINE)
CALL SEND
CALL ARO(64,192,'U')
CALL VEC(0,-128)
CALL VEC(128,0)
CALL ARO(207,49,'L')
CALL MOVETO(150,60)
CALL WRITE('R<>')
CALL MOVETO(10,200)
CALL WRITE('Z<>')
CALL MOVETO(256,52)
CALL WRITE('MESH IS ΔΔΔ BY ΔΔΔ CELLS<>',KMAX,LMAX)
CALL MOVETO(325,25)
CALL WRITE('DR=.ΔΔΔΔ, DZ=.ΔΔΔΔ<>',DR,DZ)
CALL APND
CALL ARO(128,128,'U')
RETURN
END
```

```
            SUBROUTINE FIG3
            COMMON MESS(7)
            COMMON KMAX,LMAX,MU,RHOA,DR,DZ
            COMMON NP,BPX(50),BPY(50),UNOT,VNOT,UIN,VIN
            COMMON DT,NEDIT,EPS2,BETA,NSTOP,NPIT,NDUMP,NEXP
            COMMON/MOUSE/INX,INY,INSW,SWSTAT
            COMMON/ETC/ISMX1,ISMX2,NXSP,NYSP
            LOGICAL IMF
            LOGICAL TERM
            TERM=.TRUE.
            TYPE 101
101         FORMAT(1H ,'TTY OR MOUSE INPUT?',$)
            ACCEPT 102,IDEV
102         FORMAT(A1)
            IF(IDEV.NE.'M')TERM=.FALSE.
            IMF=.TRUE.
            SMX=(KMAX-2)*DR
            SMY=(LMAX-2)*DZ
            SX=DR/NXSP
            SY=DZ/NYSP
            MM=1
1           IF(TERM)CALL WMOUSE
            IF(.NOT.TERM)CALL TTYIN
            BPX(MM)=(INX-128)*SX
            BPY(MM)=(INY-128)*SY
            IF(BPX(MM).LT.DR)BPX(MM)=0.
            IF(BPY(MM).LT.DZ)BPY(MM)=0.
            IF(BPX(MM).GT.SMX)BPX(MM)=SMX
            IF(BPX(MM).LT.DR.AND.BPY(MM).LT.DZ)GO TO 6
            IF(BPY(MM).LT.DR)GO TO 2
            IF(BPY(MM).GT.SMY)GO TO 3
            IF(IMF)GO TO 4
            CALL ARO(INX,INY,'L')
            GO TO 5
2           CALL ARO(INX,INY,'U')
            GO TO 5
3           CALL ARO(INX,INY,'D')
            IMF=.FALSE.
            ISMX1=MM
            GO TO 5
4           CALL ARO(INX,INY,'R')
5           MM=MM+1
            GO TO 1
6           ISMX2=MM
            CALL FIG4
            RETURN
            END
```

```
SUBROUTINE FIG4
COMMON MESS(7)
COMMON KMAX,LMAX,MU,RHOA,DR,DZ
COMMON NP,BPX(50),BPY(50),UNOT,VNOT,UIN,VIN
COMMON DT,NEDIT,EPS2,BETA,NSTOP,NPIT,NDUMP,NEXP
COMMON/MOUSE/INX,INY,INSW,SWSTAT
COMMON/ETC/ISMX1,ISMX2,NXSP,NYSP
CALL MOVETO(128,128)
DO 1 I=1,ISMX2
IX=(BPX(I)*NXSP)/DR+128
IY=(BPY(I)*NYSP)/DZ+128
1    CALL VECTO(IX,IY)
CALL MOVETO(732,350)
CALL WRITE('RETURN<>')
CALL SEND
RETURN
END
```

```
      SUBROUTINE TTYIN
      COMMON MESS(7)
      COMMON KMAX,LMAX,MU,RHOA,DR,DZ
      COMMON NP,BPX(50),BPY(50),UNOT,VNOT,UIN,VIN
      COMMON DT,NEDIT,EPS2,BETA,NSTOP,NPIT,NDUMP,NEXP
      COMMON/MOUSE/INX,INY,INSW,SWSTAT
      COMMON/ETC/ISMX1,ISMX2,NXSP,NYSP
      TYPE 1
1     FORMAT(1H ,'*')
      ACCEPT 2,AINX,AINY
2     FORMAT(2F)
      INX=128+(AINX*NXSP)/DR
      INY=128+(AINY*NYSP)/DZ
      RETURN
      END
```

```
      SUBROUTINE FLUID
      COMMON/MOUSE/INX,INY,INSW,SWSTAT
      DO 1 I=1,5
1     CALL FLU1(1)
2     CALL WMOUSE
      INY=(INY+128)/128
      IF(INY.GE.6)RETURN
      CALL FLU1(INY)
      GO TO 2
      END
```

```
        SUBROUTINE FLU1(J)
        COMMON MESS(7)
        COMMON KMAX,LMAX,MU,RHOA,DR,DZ
        COMMON NP,BPX(50),BPY(50),UNOT,VNOT,UIN,VIN
        COMMON DT,NEDIT,EPS2,BETA,NSTOP,NPIT,NDUMP,NEXP
        COMMON/MOUSE/INX,INY,INSW,SWSTAT
        COMMON/ETC/ISMX1,ISMX2,NXSP,NYSP
        REAL MU
        GO TO (1,4,6,9,11)J
1       TYPE 2
2       FORMAT(1H ,'INITIAL U VELOCITY=',$)
        ACCEPT 3,UNOT
3       FORMAT(F)
        GO TO 15
4       TYPE 5
5       FORMAT(1H ,'INITIAL V VELOCITY=',$)
        ACCEPT 3,VNOT
        GO TO 15
6       TYPE 7
7       FORMAT(1H ,'PARTICLE DENSITY=',$)
        ACCEPT 8,NP
8       FORMAT(I)
        GO TO 15
9       TYPE 10
10      FORMAT(1H ,'RHOA=',$)
        ACCEPT 3,RHOA
        GO TO 15
11      TYPE 12
12      FORMAT(1H ,'MU=',$)
        ACCEPT 3,MU
        GO TO 15
15      CALL FLU2
        RETURN
        END
```

```
SUBROUTINE FLU2
COMMON MESS(7)
COMMON KMAX,LMAX,MU,RHOA,DR,DZ
COMMON NP,BPX(50),BPY(50),UNOT,VNOT,UIN,VIN
COMMON DT,NEDIT,EPS2,BETA,NSTOP,NPIT,NDUMP,NEXP
COMMON/MOUSE/INX,INY,INSW,SWSTAT
COMMON/ETC/ISMX1,ISMX2,NXSP,NYSP
REAL MU
CALL BOXES(6)
CALL MOVETO(732,24)
CALL WRITE('U=△△△.△△△<>',UNOT)
CALL MOVETO(740,152)
CALL WRITE('V=△△△.△△△<>',VNOT)
CALL MOVETO(704,279)
CALL WRITE('PARTICLE DENSITY<>')
CALL MOVETO(770,258)
CALL WRITE('=△△<>',NP)
CALL MOVETO(732,410)
CALL WRITE('RHOA=△.△△△△△△△<>',RHOA)
CALL MOVETO(732,536)
CALL WRITE('MU=△.△△△△△△△<>',MU)
CALL MOVETO(732,664)
CALL WRITE('RETURN<>')
CALL SEND
RETURN
END
```

```
      SUBROUTINE CONVG
      COMMON/MOUSE/INX,INY,INSW,SWSTAT
      DO 1 I=1,3
1     CALL CONVG1(I)
2     CALL WMOUSE
      INY=(INY+128)/128
      IF(INY.GE.4)RETURN
      CALL CONVG1(INY)
      GO TO 2
      END
```

```
        SUBROUTINE CONVG1(J)
        COMMON MESS(7)
        COMMON KMAX,LMAX,MU,RHOA,DR,DZ
        COMMON NP,BPX(50),BPY(50),UNOT,VNOT,UIN,VIN
        COMMON DT,NEDIT,EPS2,BETA,NSTOP,NPIT,NDUMP,NEXP
        COMMON/MOUSE/INX,INY,INSW,SWSTAT
        COMMON/ETC/ISMX1,ISMX2,NXSP,NYSP
        GO TO (1,4,6)J
1       TYPE 2
2       FORMAT(1H ,'DT=',$)
        ACCEPT 3,DT
3       FORMAT(F)
        GO TO 8
4       TYPE 5
5       FORMAT(1H ,'CONVERGENCE EPS=',$)
        ACCEPT 3,EPS2
        GO TO 8
6       TYPE 7
7       FORMAT(1H ,'RELAXATION FACTOR=',$)
        ACCEPT 3,BETA
8       CALL CONVG2
        RETURN
        END
```

```
SUBROUTINE CONVG2
COMMON MESS(7)
COMMON KMAX,LMAX,MU,RHOA,DR,DZ
COMMON NP,BPX(50),BPY(50),UNOT,VNOT,UIN,VIN
COMMON DT,NEDIT,EPS2,BETA,NSTOP,NPIT,NDUMP,NEXP
COMMON/MOUSE/INX,INY,INSW,SWSTAT
COMMON/ETC/ISMX1,ISMX2,NXSP,NYSP
CALL BOXES(4)
CALL MOVETO(742,24)
CALL WRITE('DT=Δ.ΔΔΔΔΔ<>',DT)
CALL MOVETO(742,152)
CALL WRITE('EPS2=Δ.ΔΔΔΔΔ<>',EPS2)
CALL MOVETO(752,280)
CALL WRITE('BETA=Δ.ΔΔΔ<>',BETA)
CALL MOVETO(760,408)
CALL WRITE('RETURN<>')
CALL SEND
RETURN
END
```

```
      SUBROUTINE CNTRL
      COMMON/MOUSE/INX,INY,INSW,SWSTAT
      DO 1 I=1,6
1     CALL CNTRL1(I)
2     CALL WMOUSE
      INY=(INY+128)/128
      IF(INY.GE.7)RETURN
      CALL CNTRL1(INY)
      GO TO 2
      RETURN
      END
```

```
        SUBROUTINE CNTRL1(J)
        COMMON MESS(7)
        COMMON KMAX,LMAX,MU,RHOA,DR,DZ
        COMMON NP,BPX(50),BPY(50),UNOT,VNOT,UIN,VIN
        COMMON DT,NEDIT,EPS2,BETA,NSTOP,NPIT,NDUMP,NEXP
        COMMON/MOUSE/INX,INY,INSW,SWSTAT
        COMMON/ETC/ISMX1,ISMX2,NXSP,NYSP,FNAME
        INTEGER FNAME
        GO TO (1,4,6,8,10,13)J
1       TYPE 2
2       FORMAT(1H ,'NO. OF CYCLES BETWEEN DUMPS=',$)
        ACCEPT 3,NDUMP
        GO TO 16
3       FORMAT(I)
4       TYPE 5
5       FORMAT(1H ,'NO. OF PRESSURE ITERATIONS=',$)
        ACCEPT 3,NPIT
        GO TO 16
6       TYPE 7
7       FORMAT(1H ,'STOP AT CYCLE-',$)
        ACCEPT 3,NSTOP
        GO TO 16
8       TYPE 9
9       FORMAT(1H ,'NO. OF CYCLES BETWEEN EDITS=',$)
        ACCEPT 3,NEDIT
        GO TO 16
10      TYPE 11
11      FORMAT(1H ,'OUTPUT FILENAME:',$)
        ACCEPT 12,FNAME
12      FORMAT(A5)
        GO TO 16
13      TYPE 14
14      FORMAT(1H ,'DESCRIPTION:',$)
        ACCEPT 15,(MESS(I),I=1,7)
15      FORMAT(7A5)
16      CALL CNTRL2
        RETURN
        END
```

```
SUBROUTINE CNTRL2                                           128
COMMON MESS(7)
COMMON KMAX,LMAX,MU,RHOA,DR,DZ
COMMON NP,BPX(50),BPY(50),UNOT,VNOT,UIN,VIN
COMMON DT,NEDIT,EPS2,BETA,NSTOP,NPIT,NDUMP,NEXP
COMMON/MOUSE/INX,INY,INSW,SWSTAT
COMMON/ETC/ISMX1,ISMX2,NXSP,NYSP,FNAME
INTEGER FNAME
CALL BOXES(7)
CALL MOVETO(752,24)
CALL WRITE('NDUMP=ΔΔ<>',NDUMP)
CALL MOVETO(752,152)
CALL WRITE('NPIT=ΔΔ<>',NPIT)
CALL MOVETO(752,280)
CALL WRITE('NSTOP=ΔΔΔ<>',NSTOP)
CALL MOVETO(752,408)
CALL WRITE('NEDIT=ΔΔ<>',NEDIT)
CALL MOVETO(752,536)
CALL WRITE('FNAME=<>')
CALL WRITES(FNAME)
CALL MOVETO(752,664)
CALL WRITE('DESCRIPTION<>')
CALL MOVETO(760,792)
CALL WRITE('RETURN<>')
CALL SEND
RETURN
END
```

```
SUBROUTINE CHECK
COMMON MESS(7)
COMMON KMAX,LMAX,MU,RHOA,DR,DZ
COMMON NP,BPX(50),BPY(50),UNOT,VNOT,UIN,VIN
COMMON DT,NEDIT,EPS2,BETA,NSTOP,NPIT,NDUMP,NEXP
COMMON/MOUSE/INX,INY,INSW,SWSTAT
COMMON/ETC/ISMX1,ISMX2,NXSP,NYSP
      IY1=512-BPX(1)*NXSP/DR
      CALL MOVETO(150,IY1)
      DO 1 J=2,ISMX1-1
      IX=150+BPY(J)*NYSP/DZ
      IY=512-BPX(J)*NXSP/DR
1     CALL ZIPTO(IX,IY)
      IY1=512+BPX(1)*NXSP/DR
      CALL MOVETO(150,IY1)
      DO 2 J=2,ISMX1-1
      IX=150+BPY(J)*NYSP/DZ
      IY=512+BPX(J)*NXSP/DR
2     CALL ZIPTO(IX,IY)
      ISM=ISMX1+1
      IX1=150+BPY(ISM)*NYSP/DZ
      CALL MOVETO(IX1,512)
      DO 3 J=ISM+1,ISMX2-1
      IX=150+BPY(J)*NYSP/DZ
      IY=512+BPX(J)*NXSP/DR
3     CALL ZIPTO(IX,IY)
      CALL MOVETO(IX1,512)
      DO 4 J=ISM+1,ISMX2-1
      IX=150+BPY(J)*NYSP/DZ
      IY=512-BPX(J)*NYSP/DR
4     CALL ZIPTO(IX,IY)
      IYB=512-BPX(1)*NXSP/DR
      IYT=512+BPX(1)*NXSP/DZ
      CALL SEND
      CALL ARO(140,IYT,'U')
      CALL VECTO(140,525)
      CALL ARO(140,IYB,'D')
      CALL VECTO(140,499)
      CALL MOVETO(52,504)
      CM=BPX(1)*2.
      CALL WRITE('∆∆.∆∆ CM<>',CM)
      CALL ARO(150,IYB,'D')
      CALL VECTO(150,512)
      LNG=512-IYB
      IXT=150+LNG
      CALL ARO(IXT,512,'L')
      CALL VECTO(150,512)
      CALL MOVETO(160,IYB+5)
      CALL WRITE('R<>')
      CALL MOVETO(IXT+12,504)
      CALL WRITE('Z<>')
      ISM1=ISMX1-1
      IYB=512-BPX(ISM1)*NXSP/DR
      IYT=512+BPX(ISM1)*NXSP/DR
      CALL ARO(985,IYT,'U')
      CALL VECTO(985,532)
      CALL ARO(985,IYB,'D')
```

```
      CALL VECTO(985,492)
      CALL MOVETO(955,522)
      CM=BPX(ISM1)*2.
      CALL WRITE('ΔΔ.ΔΔ<>',CM)
      CALL MOVETO(973,503)
      CALL WRITE('CM<>')
      IY1=IYT+20
      CALL ARO(950,IY1,'L')
      CALL VECTO(600,IY1)
      CALL ARO(150,IY1,'R')
      CALL VECTO(500,IY1)
      CM=BPY(ISMX1)*2.
      IY1=IY1-8
      CALL MOVETO(504,IY1)
      CALL WRITE('ΔΔ.ΔΔ CM<>',CM)
      IX1=BPY(ISM)*NXSP/DZ+300
      CALL MOVETO(IX1,517)
      CALL VEC(-60,0)
      CALL VEC(0,10)
      CALL VEC(-20,-15)
      CALL VEC(20,-15)
      CALL VEC(0,10)
      CALL VEC(60,0)
      CALL MOVE(5,-3)
      CALL WRITE('FLOW<>')
      CALL MOVETO(348,124)
      CALL WRITE('U-IN=ΔΔΔΔ.ΔΔ<>',UIN)
      CALL MOVETO(348,164)
      CALL WRITE('V-IN=ΔΔΔΔ.ΔΔ<>',VIN)
      CALL MOVETO(515,124)
      CALL WRITE('U-NOT=ΔΔΔΔ.ΔΔ<>',UNOT)
      CALL MOVETO(515,164)
      CALL WRITE('V-NOT=ΔΔΔΔ.ΔΔ<>',VNOT)
      CALL MOVETO(412,900)
      DO 5 J=1,7
    5 CALL WRITES(MESS(J))
      CALL APND
      RETURN
      END
```

```fortran
      SUBROUTINE OUTP
      COMMON MESS(7)
      COMMON KMAX,LMAX,MU,RHOA,DR,DZ
      COMMON NP,BPX(50),BPY(50),UNOT,VNOT,UIN,VIN
      COMMON DT,NEDIT,EPS2,BETA,NSTOP,NPIT,NDUMP,NEXP
      COMMON/MOUSE/INX,INY,INSW,SWSTAT
      COMMON/ETC/ISMX1,ISMX2,NXSP,NYSP,FNAME
      DIMENSION IDT(2)
      REAL MU
      INTEGER FNAME
      CALL OFILE(23,FNAME)
      TYPE 1
1     FORMAT(1H ,'LINEFEED TO NEW PAGE,CR')
      ACCEPT 2,DUMMY
2     FORMAT(A1)
      CALL DATE(IDT)
      TYPE 3
3     FORMAT(1H ,T37,'ABMAC')
      TYPE 4
4     FORMAT(1H ,T35,'UNIVERSITY OF UTAH')
      TYPE 5,IDT(1),IDT(2)
5     FORMAT(1H ,T35,A5,A4)
      TYPE 6
6     FORMAT(1H-)
      TYPE 7,(MESS(I),I=1,7)
7     FORMAT(1H ,7A5)
      WRITE(23,7)(MESS(I),I=1,7)
      MOPT=0
      TYPE 8,KMAX,LMAX,NEXP,MOPT
8     FORMAT(1H ,4I)
      WRITE(23,8)KMAX,LMAX,NEXP,MOPT
      SMIN=.01
      EPS1=.2
      TYPE 9,SMIN,EPS1
9     FORMAT(1H ,2F)
      WRITE(23,9)SMIN,EPS1
      GZ=0.
      GR=0.
      TYPE 10,GZ,GR,MU,RHOA
10    FORMAT(1H ,4F)
      WRITE(23,10)GZ,GR,MU,RHOA
      TYPE 11,DR
11    FORMAT(1H ,F)
      WRITE(23,11)DR
      TYPE 11,DZ
      WRITE(23,11)DZ
      KA=2
      KB=KMAX-1
      LA=2
      LB=LMAX-1
      TYPE 12,NP,KA,KB,LA,LB
12    FORMAT(1H ,5I)
      WRITE(23,12)NP,KA,KB,LA,LB
      IZERO=0
      ZERO=0.
      SMALL=-0.0001
      ISM=ISMX1-1
```

```
            TYPE 13,ZERO,ZERO
            WRITE(23,13)ZERO,ZERO
13          FORMAT(1H ,2F)
            DO 14 J=1,ISMX2
            TYPE 13,BPX(J),BPY(J)
14          WRITE(23,13)BPX(J),BPY(J)
            TYPE 15,IZERO
15          FORMAT(1H ,I)
            WRITE(23,15)IZERO
            KA=1
            KB=KMAX
            LA=1
            LB=LMAX
            KIN=0
            KOUT=0
            TYPE 16,KA,KB,LA,LB,UNOT,VNOT,KIN,KOUT
16          FORMAT(1H ,4I,2F,2I)
            WRITE(23,16)KA,KB,LA,LB,UNOT,VNOT,KIN,KOUT
            KA=2
            KB=BPX(1)/DR+2
            LA=1
            LB=1
            KOUT=1
            TYPE 16,KA,KB,LA,LB,UNOT,VNOT,KIN,KOUT
            WRITE(23,16)KA,KB,LA,LB,UNOT,VNOT,KIN,KOUT
            KA=2
            KB=KMAX-1
            LA=LMAX
            LB=LMAX
            VVEL=VIN
            UVEL=UIN
            KOUT=0
            KIN=1
            TYPE 16,KA,KB,LA,LB,UVEL,VVEL,KIN,KOUT
            WRITE(23,16)KA,KB,LA,LB,UVEL,VVEL,KIN,KOUT
            TYPE 15,IZERO
            WRITE(23,15)IZERO
            NBP=2*(KMAX-2)
            XXA=.05
            YYA=DZ*(LMAX-2)+.05
            DDR=DR/2
            DDZ=0.
            TYPE 17,NBP,XXA,YYA,DDR,DDZ
17          FORMAT(1H ,I,4F)
            WRITE(23,17)NBP,XXA,YYA,DDR,DDZ
            TYPE 9,BPX(1),SMALL
            WRITE(23,9)BPX(1),SMALL
            DO 18 I=2,ISMX1-2
            TYPE 9,BPX(I),BPY(I)
18          WRITE(23,9)BPX(I),BPY(I)
            ITWO=2
            TYPE 19,BPX(ISM),BPY(ISM),ITWO
19          FORMAT(1H ,2F,I)
            WRITE(23,19)BPX(ISM),BPY(ISM),ITWO
            IONE=1
            ISM2=ISMX1+2
            ISM=ISMX2-1
```

```
            BPX(ISM2)=SMALL
            DO 20 I=ISM2,ISMX2-2
            TYPE 9,BPX(I),BPY(I)
20          WRITE(23,9)BPX(I),BPY(I)
            TYPE 19,BPX(ISM),BPY(ISM),IONE
            WRITE(23,19)BPX(ISM),BPY(ISM),IONE
            ICRT=1
            CRTRA=3.2
            CRTRB=6.
            CRTZA=16.
            CRTZB=.2885
            XMAX=.2885
            YMAX=.9
            TYPE 21,ICRT,CRTRA,CRTRB,CRTZA,CRTZB,XMAX,YMAX
21          FORMAT(1H ,I,6F)
            WRITE(23,21)ICRT,CRTRA,CRTRB,CRTZA,CRTZB,XMAX,YMAX
            TYPE 11,DT
            WRITE(23,11)DT
            TYPE 15,NEDIT
            WRITE(23,15)NEDIT
            TYPE 11,EPS1
            WRITE(23,11)EPS1
            TYPE 11,EPS2
            WRITE(23,11)EPS2
            TYPE 11,BETA
            WRITE(23,11)BETA
            NGEN='N'
            TYPE 22,NGEN
22          FORMAT(1H ,A1)
            WRITE(23,22)NGEN
            TYPE 11,SMIN
            WRITE(23,11)SMIN
            TYPE 15,NSTOP
            WRITE(23,15)NSTOP
            TYPE 15,NPIT
            WRITE(23,15)NPIT
            TYPE 15,NDUMP
            WRITE(23,15)NDUMP
            END FILE 23
            RETURN
            END
```

```
SUBROUTINE ARO(INX,INY,DIR)
INTEGER DIR
N1=5
N2=15
IF(DIR.EQ.'U')INY=INY-15
IF(DIR.EQ.'D')INY=INY+15
IF(DIR.EQ.'L')INX=INX-15
IF(DIR.EQ.'R')INX=INX+15
CALL MOVETO(INX,INY)
IF(DIR.EQ.'R'.OR.DIR.EQ.'U')N2=-N2
IF(DIR.EQ.'U'.OR.DIR.EQ.'D')GO TO 1
CALL VEC(0,N1)
CALL VEC(N2,-N1)
CALL VEC(-N2,-N1)
CALL VEC(0,N1)
CALL APND
RETURN
1       CALL VEC(-N1,0)
CALL VEC(N1,-N2)
CALL VEC(N1,N2)
CALL VEC(-N1,0)
CALL APND
RETURN
END
```

```
      SUBROUTINE BOXES(N)
      DO 1 I=1,N
      JPOS=(I*128)-128
      CALL MOVETO(704,JPOS)
1     CALL BOX
      RETURN
      END
```

```
SUBROUTINE BOX
CALL VEC(0,64)
CALL VEC(192,0)
CALL VEC(0,-64)
CALL VEC(-192,0)
RETURN
END
```

APPENDIX II

THE COMPUTATION INITIALIZATION PROGRAM

Routine Name	Function
MAIN	Establish common areas
MACMAIN	Control initialization, writes out data file
GEN	Marks cells and initializes
GENB	Computes normals describing boundary segments
REFLAG	Readjusts cell flags in surface
EDIT	Lists initial values for all problem variables

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```
      COMMON NVAC,NGEN,UAC,VAC,TM1,TM2,TM3
      COMMON NCYCLE,NSTOP,NEDTM,NEDIT,OPE
      COMMON TIME,EDTIM,EDDT,NPIT
      COMMON BETA,EPS2,DT,VMAX,UMAX,RELAX,CUT
      COMMON SMIN,EPS1,NBMAX,UBTO,VBTO,UBND,VBND
      COMMON UM,MU,RHOA,GR,GZ,G,ISEC
      COMMON VIN,UIN,DKP,DLP,NBP,DDR,DDZ
      COMMON NEXP,NEXPP,NPART,NDIV
      COMMON NGRID,KMAX,LMAX,KMAXZ,LMAXZ,KMAXZZ,LMAXZZ
      COMMON KDMN,LDMN,KDMX,LDMX,MESS(7)
      COMMON ICRT,XMAX,YMAX,CRTRA,CRTRB,CRTZA,CRTZB
      COMMON ITLST,IO2,IZ,GAMA,PGAS,PGASZ,PAMB,GASV,GASVZ
      COMMON NF,NG,NIT,H,XG,HH,HV,GG,FUDGE,HTAL,CRAX,DELZ
      COMMON BPX(300),PTX(300),RMP(300),RNP(300),XB(300)
      COMMON BPY(300),PTY(300),ZMP(300),ZNP(300),YB(300)
      COMMON DS(300),IBP(300)
      COMMON R(150),Z(150),RB(150),ZB(150)
      COMMON DRB(150),DZB(150)
      COMMON M(2500)
      COMMON RP1(5000),RP2(5000)
      COMMON UAVG(2500),VAVG(2500)
      COMMON P(2500),U(2500),ETA(2500),V(2500),PSI(2500)
      COMMON DNORX(2500),DNORY(2500),PNORX(2500),PNORY(2500)
      COMMON NPRTA(2500),NPRTB(2500),MPRTA(2500),MPRTB(2500)
      COMMON SNC(2500),DR,DZ
      COMMON NBC(300),IPX(300)
      COMMON NDEV1,NDEV2
      COMMON/FLAG1/FLAG1
      REAL MU
      INTEGER AND,OR,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     * FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,ARB
      DATA INTRE,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     * FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,ARB/1,2,4,8,16,32,
     * 64,128,256,512,1024,2048,4096,8192,16384,32768/
      DATA MASK1,MASK2,MASK3,MASK4,MASK5,MASK6,
     * MASK7,MASK8/0777777777757,0777777773777,
     * 0777777677777,0777777777773,0777777777767,
     * 0777777737777,0777777757777,0777777767777/
      DOUBLE PRECISION U,V,PSI,ETA,P
      DOUBLE PRECISION UMAX,VMAX
      PI=3.1415926
      INTEGER FLAG1
      FLAG1=1
      CALL MACMAIN
      END
      SUBROUTINE MACMAIN
      COMMON NVAC,NGEN,UAC,VAC,TM1,TM2,TM3
      COMMON NCYCLE,NSTOP,NEDTM,NEDIT,OPE
      COMMON TIME,EDTIM,EDDT,NPIT
      COMMON BETA,EPS2,DT,VMAX,UMAX,RELAX,CUT
      COMMON SMIN,EPS1,NBMAX,UBTO,VBTO,UBND,VBND
      COMMON UM,MU,RHOA,GR,GZ,G,ISEC
      COMMON VIN,UIN,DKP,DLP,NBP,DDR,DDZ
      COMMON NEXP,NEXPP,NPART,NDIV
      COMMON NGRID,KMAX,LMAX,KMAXZ,LMAXZ,KMAXZZ,LMAXZZ
      COMMON KDMN,LDMN,KDMX,LDMX,MESS(7)
      COMMON ICRT,XMAX,YMAX,CRTRA,CRTRB,CRTZA,CRTZB
```

```
        COMMON ITLST,IO2,I2,GAMA,PGAS,PGAS2,PAMB,GASV,GASV2
        COMMON NF,NG,NIT,H,XG,HH,HV,GG,FUDGE,NTAL,CRAX,DEL2
        COMMON BPX(300),PTX(300),RMP(300),RNP(300),XB(300)
        COMMON BPY(300),PTY(300),ZMP(300),ZNP(300),YB(300)
        COMMON DS(300),IBP(300)
        COMMON R(150),Z(150),RB(150),ZB(150)
        COMMON DRB(150),DZB(150)
        COMMON M(2500)
        COMMON RP1(5000),RP2(5000)
        COMMON UAVG(2500),VAVG(2500)
        COMMON P(2500),U(2500),ETA(2500),V(2500),PSI(2500)
        COMMON DNORX(2500),DNORY(2500),PNORX(2500),PNORY(2500)
        COMMON NPRTA(2500),NPRTB(2500),MPRTA(2500),MPRTB(2500)
        COMMON SNC(2500),DR,DZ
        COMMON NBC(300),IPX(300)
        COMMON NDEV1,NDEV2
        COMMON/FLAG1/FLAG1
        REAL MU
        INTEGER AND,OR,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     *  FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,ARB
        DATA INTRB,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     *  FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,ARB/1,2,4,8,16,32,
     *  64,128,256,512,1024,2048,4096,8192,16384,32768/
        DATA MASK1,MASK2,MASK3,MASK4,MASK5,MASK6,
     *  MASK7,MASK8/0777777777757,0777777773777,
     *  0777777677777,0777777777773,0777777777767,
     *  0777777737777,0777777757777,0777777767777/
        DOUBLE PRECISION U,V,PSI,ETA,P
        DOUBLE PRECISION UR,UL,VB,VT,UBAR,VBAR
        DOUBLE PRECISION UTOP,VLEFT,VRGHT
        DOUBLE PRECISION TEMPL,TEMPR,UBOT
        DOUBLE PRECISION UMAX,VMAX
        PI=3.1415926
        NTAL=0
        TYPE 2
2       FORMAT(1H ,'NEW GENERATOR?',$)
        ACCEPT 4,NIXE
3       FORMAT(I)
4       FORMAT(A1)
        IF(NIXE.EQ.'N') GO TO 7
        TYPE 5
5       FORMAT(1H ,'INPUT FROM:',$)
        ACCEPT 6,NDEV1
6       FORMAT(A3)
        IF(NDEV1.EQ.'TTY') NDEV1=5
        IF(NDEV1.EQ.'DSK') NDEV1=21
        IF(NDEV1.EQ.21)GO TO 601
        GO TO 605
601     TYPE 602
602     FORMAT(1H ,'INPUT FILE:',$)
        ACCEPT 603,NME
603     FORMAT(A5)
        NME=NME+32
        CALL IFILE(21,NME)
605     CALL GEN
        NEDTM=0
        NLIMT=0
```

```
         NUMPT=1
         OPE=1.
         GO TO 11
7        TYPE 8,NCYCLE
8        FORMAT(1H ,'READY AT CYCLE ',I3)
         TYPE 9
9        FORMAT(1H ,'CHANGE RUN TIME SYSTEM?')
         ACCEPT 10,NYS
10       FORMAT(A1)
         IF(NYS.EQ.'N') GO TO 33
         NDEV1=5
11       TYPE 12
12       FORMAT(1H ,'DT=',$)
         READ(NDEV1,13) DT
         TYPE 24
13       FORMAT(F)
         TYPE 14
14       FORMAT(1H ,'NO. OF CYCLES BETWEEN EDITS=',$)
         READ(NDEV1,15)NEDIT
         TYPE 24
15       FORMAT(I)
         TYPE 16
16       FORMAT(1H ,'BOUNDARY SENSING PARAMETER=',$)
         READ(NDEV1,13) EPS1
         TYPE 24
         TYPE 17
17       FORMAT(1H ,'CONVERGENCE EPSILON=',$)
         READ(NDEV1,13) EPS2
         TYPE 24
         TYPE 18
18       FORMAT(1H ,'OVER-RELAXATION FACTOR=',$)
         READ(NDEV1,13) BETA
         TYPE 24
         TYPE 19
19       FORMAT(1H ,'BACKWARDS DIFFERENCING?')
         READ(NDEV1,20) NGEN
         TYPE 24
         IF(NGEN.EQ.'Y') NGEN=0
         IF(NGEN.EQ.'N') NGEN=1
20       FORMAT(A1)
         TYPE 21
21       FORMAT(1H ,'FULL CELL EPSILON=',$)
         READ(NDEV1,13) SMIN
         TYPE 24
         TYPE 22
22       FORMAT(1H ,'STOP AT CYCLE-',$)
         READ(NDEV1,15) NSTOP
         TYPE 24
23       CONTINUE
24       FORMAT(1H )
         TYPE 25
25       FORMAT(1H ,'PRESSURE ITERATIONS=',$)
         READ(NDEV1,15) NPIT
         TYPE 24
         TYPE 26
26       FORMAT(1H ,'NO. OF CYCLES BETWEEN DUMPS=',$)
         READ(NDEV1,15) NDUMP
```

```
      TYPE 24
      KMAXZ=KMAX-1
      LMAXZ=LMAX-1
      KMAXZZ=KMAX-2
      LMAXZZ=LMAX-2
      NGRID=KMAX*LMAX
      DTMAX=DR**2*DZ**2/(DR**2+DZ**2)
      DTMAX=.4*DTMAX/(MU+.000001)*RHOA
      DT=.5*(DT+DTMAX)-.5*ABS(DT-DTMAX)
      DTMAX=DT
      RELAX=.2*RHOA*DR**2/DT
      NSWR=2
      TFV=.25
      TAU=2.0
      FV=.5
      IF(G)28,28,29
28    CRAX=RHOA
      GO TO 30
29    CRAX=G*Z(LMAX)
      CRAX=1./CRAX
30    GO=G
      IF(NTAL.EQ.'N') GO TO 33
      CALL EDIT
32    CONTINUE
33    CONTINUE
      NME=NME+2
      CALL OFILE(22,NME)
      WRITE(22)NGEN
       WRITE(22)NCYCLE,NSTOP,NEDTM,NEDIT,OPE
       WRITE(22)TIME,EDTIM,EDDT,NPIT
       WRITE(22)BETA,EPS2,DT,VMAX,UMAX,RELAX,CUT
       WRITE(22)SMIN,EPS1,NBMAX,UBTO,VBTO,UBND,VBND
       WRITE(22)UM,MU,RHOA,GR,GZ,G,ISEC
       WRITE(22)VIN,UIN,DKP,DLP,NBP,DDR,DDZ
       WRITE(22)NEXP,NEXPP,NPART,NDIV
       WRITE(22)NGRID,KMAX,LMAX,KMAXZ,LMAXZ,KMAXZZ,LMAXZZ
       WRITE(22)KDMN,LDMN,KDMX,LDMX,MESS
      WRITE(22)ICRT,XMAX,YMAX,CRTRA,CRTRB,CRTZA,CRTZB
       WRITE(22)ITEST,IOZ,IZ,GAMA,PGAS,PGASZ,PAMB,GASV,GASVZ
       WRITE(22)NF,NG,NIT,H,XG,HH,HV,GO,FUDGE,NTAL,CRAX,DELZ
       WRITE(22)R,Z,RB,ZB
       WRITE(22)DRB,DZB
       WRITE(22)M
       WRITE(22)P,U,ETA,V,PSI
       WRITE(22)DNORX,DNORY,PNORX,PNORY
      WRITE(22)DR,DZ
      END FILE 22
      RETURN
      END
```

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```
          SUBROUTINE GEN
          COMMON NVAC,NGEN,UAC,VAC,TM1,TM2,TM3
          COMMON NCYCLE,NSTOP,NEDTM,NEDIT,OPE
          COMMON TIME,EDTIM,EDDT,NPIT
          COMMON BETA,EPS2,DT,VMAX,UMAX,RELAX,CUT
          COMMON SMIN,EPS1,NBMAX,UBTO,VBTO,UBND,VBND
          COMMON UM,MU,RHOA,GR,GZ,G,ISEC
          COMMON VIN,UIN,DKP,DLP,NBP,DDR,DDZ
          COMMON NEXP,NEXPP,NPART,NDIV
          COMMON NGR,KMAX,LMAX,KMAXZ,LMAXZ,KMAXZZ,LMAXZZ
          COMMON KDMN,LDMN,KDMX,LDMX,MESS(7)
          COMMON ICRT,XMAX,YMAX,CRTRA,CRTRB,CRTZA,CRTZB
          COMMON ITEST,IOZ,IZ,GAMA,PGAS,PGASZ,PAMB,GASV,GASVZ
          COMMON NF,NG,NIT,H,XG,HH,HV,GG,FUDGE,NTAL,CRAX,DELZ
          COMMON DPX(300),PTX(300),RMP(300),RNP(300),XB(300)
          COMMON BPY(300),PTY(300),ZMP(300),ZNP(300),YB(300)
          COMMON DS(300),IBP(300)
          COMMON R(150),Z(150),RB(150),ZB(150)
          COMMON DRB(150),DZB(150)
          COMMON M(2500)
          COMMON RP1(5000),RP2(5000)
          COMMON UAVG(2500),VAVG(2500)
          COMMON P(2500),U(2500),ETA(2500),V(2500),PSI(2500)
          COMMON DNORX(2500),DNORY(2500),PNORX(2500),PNORY(2500)
          COMMON NPRTA(2500),NPRTB(2500),MPRTA(2500),MPRTB(2500)
          COMMON SNC(2500),DR,DZ
          COMMON NBC(300),IPX(300)
          COMMON NDEV1,NDEV2
          COMMON/FLAG1/FLAG1
          REAL MU
          INTEGER AND,OR,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     *    FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,ARB
          DATA INTRF,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     *    FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,ARB/1,2,4,8,16,32,
     *    64,128,256,512,1024,2048,4096,8192,16384,32768/
          DATA MASK1,MASK2,MASK3,MASK4,MASK5,MASK6,
     *    MASK7,MASK8/07777777777757,07777777773777,
     *    07777776677777,07777777777773,07777777777767,
     *    07777777737777,07777777757777,07777777767777/
          DOUBLE PRECISION UMAX,VMAX
          DOUBLE PRECISION U,V,PSI,ETA,P
          PI=3.1415926
          LOGICAL TEST
          PI=3.1415926
          TYPE 1001
          TYPE 1009
 1001     FORMAT(1H ,'HEADING')
          READ(NDEV1,1)(MESS(I),I=1,7)
 1        FORMAT(7A5)
 2        FORMAT(4I)
 3        FORMAT(2F)
 4        FORMAT(4F)
          TYPE 1002
          TYPE 1009
 1002     FORMAT(1H ,'KMAX,LMAX,NEXP,MOPT')
          READ(NDEV1,2)KMAX,LMAX,NEXP,MOPT
          TYPE 1003
```

```
         TYPE 1009
1003     FORMAT(1H ,'SMIN,EPS1')
         READ(NDEV1,3)SMIN,EPS1
         TYPE 1004
         TYPE 1009
1004     FORMAT(1H ,'GZ,GR,MU,RHOA')
         READ(NDEV1,4)GZ,GR,MU,RHOA
         G=SQRT(GZ**2+GR**2)
         NEXPP=NEXP+1
         KMAXZ=KMAX-1
         KMAXZZ=KMAX-2
         LMAXZ=LMAX-1
         LMAXZZ=LMAX-2
         NCYCLE=0
         TIME=0.
         NDIV=0
         CUT=.0000001
         UM=MU
         NGRID=KMAX*LMAX
         TYPE 1005
C        GENERATE COORDINATES, AND CONSTANTS
C
1005     FORMAT(1H ,'DR')
         READ(NDEV1,5)DR
         TYPE 1006
         TYPE 1009
1006     FORMAT(1H ,'DZ')
         READ(NDEV1,5)DZ
5        FORMAT(F)
         RB(1)=1./10.0**10
         DO 6 K=1,KMAXZ
6        RB(K+1)=RB(K)+DR
         ZB(1)=0.
         DO 7 L=1,LMAXZ
7        ZB(L+1)=ZB(L)+DZ
         R(1)=-.5*RB(2)
         Z(1)=-.5*ZB(2)
         DO 8 K=2,KMAX
8        R(K)=(RB(K)+RB(K-1))*0.5
         DO 9 L=2,LMAX
9        Z(L)=(ZB(L)+ZB(L-1))*0.5
         DO 10 K=1,KMAXZ
10       DRB(K)=R(K+1)-R(K)
         DO 11 L=1,LMAXZ
11       DZB(L)=Z(L+1)-Z(L)
         DO 12 K=1,NGRID
         P(K)=0.
         U(K)=0.
         V(K)=0.
         ETA(K)=0.
         PSI(K)=0.
         UAVG(K)=0.
         VAVG(K)=0.
         M(K)=0
         DNORX(K)=0.
         DNORY(K)=0.
         PNORX(K)=0.
```

```
12        PRIORY(K)=0.
          UBND=C.
          VBND=0.
          DO 13 L=2,LMAX2
          KMM=(L-1)*KMAX
          DO 13 K=2,KMAX2
          KM=K+KMM
13        M(KM)=(M(KM).OR.EMP)
C         READ IN A SET OF POINTS SPECIFYING A CLOSED CURVE, LYING
C         IN THE REGION BOUNDED BY KA,KB,LA,LB. PARTICLES ARE
C         GENERATED AT DENSITY NP**2 INSIDE THIS AREA. ANY NUMBER
C         OF CLOSED REGIONS ALLOWED.
C
          N=0
          TYPE 1007
          TYPE 1009
1007      FORMAT(1H ,'NP,KA,KB,LA,LB')
14        READ(NDEV1,15)NP,KA,KB,LA,LB
15        FORMAT(5I)
          IF(NP) 31,31,16
16        TYPE 1008
1008      FORMAT(1H ,'BPX,BPY')
          TYPE 1009
1009      FORMAT(1H )
          READ(NDEV1,17)BPX(1),BPY(1)
17        FORMAT(2F)
          MM=2
18        READ(NDEV1,17)BPX(MM),BPY(MM)
          IF(BPX(1).EQ.BPX(MM).AND.BPY(1).EQ.BPY(MM)) GO TO 21
19        MM=MM+1
          GO TO 18
21        MMAX=MM-1
          DKP=DR/NP
          DLP=DZ/NP
          DO 28 L=LA,LB
          KMM=(L-1)*KMAX
          DO 28 K=KA,KB
          KM=K+KMM
          RA=RB(K-1)-0.5*DKP
          ZA=ZB(L-1)-0.5*DLP
          DO 28 LP=1,NP
          ZZ=ZA+DLP*LP
          DO 28 KP=1,NP
          RR=RA+DKP*KP
          ANGLE=0.
          DO 26 J=1,MMAX
          X1=BPX(J)-RR
          X2=BPX(J+1)-RR
          Y1=BPY(J)-ZZ
          Y2=BPY(J+1)-ZZ
          CROSSP=X1*Y2-X2*Y1
          FMAG=(X1**2+Y1**2)*(X2**2+Y2**2)
          FMAG=SQRT(FMAG)
          ALPHA=ASIN(CROSSP/FMAG)
          DOT=X1*X2+Y1*Y2
          IF(DOT)22,25,25
22        IF(ALPHA) 23,24,24
```

```
23          ANGLE=ANGLE-PI-ALPHA
            GO TO 26
24          ANGLE=ANGLE+PI-ALPHA
            GO TO 26
25          ANGLE=ANGLE+ALPHA
26          CONTINUE
            IF(ABS(ANGLE)-0.0001)28,27,27
27          N=N+1
            NPRTA(KM)=NPRTA(KM)+1
            M(KM)=(M(KM).OR.FULL)
            M(KM)=(M(KM).AND.MASK1)
            RP1(N)=RR
            RP2(N)=ZZ
28          CONTINUE
            NDIV=N
            NPART=N
            GO TO 14
31          CONTINUE
C           INPUT CELL VELOCITIES. KIN=0,KOUT=0 FOR INTERIOR CELLS.
C           FOR INFLOW, SET KIN=1, FOR OUTFLOW SET KOUT=1.
C
32          TYPE 1010
            TYPE 1009
1010        FORMAT(1H ,'KA,KB,LA,LB,UVEL,VVEL,KIN,KOUT')
            READ(NDEV1,33)KA,KB,LA,LB,UVEL,VVEL,KIN,KOUT
33          FORMAT(4I,2F,2I)
            IF(KA) 38,38,34
34          DO 37 L=LA,LB
            KMM=(L-1)*KMAX
            DO 37 K=KA,KB
            KM=K+KMM
            U(KM)=UVEL
            V(KM)=VVEL
            IF(KIN.EQ.0) GO TO 35
            UIN=UVEL
            VIN=VVEL
35          M(KM)=(M(KM).OR.(KIN*64))
            M(KM)=(M(KM).OR.(KOUT*128))
37          CONTINUE
            GO TO 32
C           SPECIFY A LINE OF INPUT PARTICLES LYING JUST OUTSIDE
C           INPUT BOUNDARY. NBP= NUMBER OF PARTICLES, XXA AND
C           YYA ARE THE COORDINATES OF THE FIRST POINT. DDR AND
C           DDZ GIVE THE SPACING.
C
38          TYPE 1011
            TYPE 1009
1011        FORMAT(1H ,'NBP,XXA,YYA,DDR,DDZ')
            READ(NDEV1,39)NBP,XXA,YYA,DDR,DDZ
39          FORMAT(1,4F)
            IF(NBP)43,43,40
40          MM=NBP+1
            NPART=NPART+NBP
            DO 41 N=NPART,MM,-1
            RP1(N)=RP1(N-NBP)
41          RP2(N)=RP2(N-NBP)
            RP1(1)=XXA
```

```
            RP2(J)=YYA
            K=(XXA+DR)/DR+1
            L=(YYA+DZ)/DZ+1
            KM=K+(L-1)*KMAX
            NBC(J)=KM
            NPRTA(KM)=NPRTA(KM)+1
            DO 42 N=2,NBP
            XXA=XXA+DDR
            YYA=YYA+DDZ
            RP1(N)=XXA
            RP2(N)=YYA
            K=(XXA+DR)/DR+1
            L=(YYA+DZ)/DZ+1
            KM=K+(L-1)*KMAX
            NPRTA(KM)=NPRTA(KM)+1
42          NBC(N)=KM
            NDIV=NPART
43          CONTINUE
            CALL GENB
C           SET NOBB AND NCORB FLAGS.
C
            LOGICAL TEST
            DO 57 L=2,LMAXZ
            KTT=L*KMAX
            DO 57 K=2,KMAXZ
            KT=KTT+K
            KM=KT-KMAX
            KB=KM-KMAX
            ITFX=1
            IF((M(KM).AND.OB).EQ.OB) GO TO 44
            GO TO 57
44          IF(DNORX(KM))45,49,47
45          TEST=(PTX(ISEC).EQ.RB(K)).OR.(PTX(1).EQ.RB(K))
            IF(ITFX.EQ.0) TEST=.FALSE.
            IF(((M(KM+1).AND.OB).EQ.OB).OR.((M(KM+1).AND.FULL).EQ.FULL)
     *      .OR.TEST) GO TO 49
            M(KM+1)=(M(KM+1).OR.COR)
            GO TO 49
47          TEST=(PTX(ISEC).EQ.RB(K-1)).OR.(PTX(1).EQ.RB(K-1))
            IF(ITFX.EQ.0) TEST=.FALSE.
            IF(((M(KM-1).AND.OB).EQ.OB).OR.((M(KM-1).AND.FULL).EQ.FULL)
     *      .OR.TEST) GO TO 49
            M(KM-1)=(M(KM-1).OR.COR)
49          IF(DNORY(KM)) 50,54,52
50          TEST=(PTY(ISEC).EQ.ZB(L)).OR.(PTY(1).EQ.ZB(L))
            IF(ITFX.EQ.0) TEST=.FALSE.
            IF(((M(KT).AND.OB).EQ.OB).OR.((M(KT).AND.FULL).EQ.FULL)
     *      .OR.TEST) GO TO 54
            M(KT)=(M(KT).OR.COR)
            GO TO 54
52          TEST=(PTY(ISEC).EQ.ZB(L-1)).OR.(PTY(1).EQ.ZB(L))
            IF(ITFX.EQ.0) TEST=.FALSE.
            IF(((M(KB).AND.OB).EQ.OB).OR.((M(KB).AND.FULL).EQ.FULL)
     *      .OR.TEST) GO TO 54
            M(KB)=(M(KB).OR.COR)
54          CONTINUE
            IF(ITFX.EQ.1) GO TO 55
```

```
            GO TO 57
55          TEST=((M(KB).AND.COR).EQ.COR).OR.((M(KT).AND.COR).EQ.COR)
     *      .OR.((M(KM-1).AND.COR).EQ.COR).OR.((M(KM+1).AND.COR).EQ.COR)
            IF(((M(KM).AND.OB).EQ.OB).AND.(.NOT.TEST)) GO TO 56
            GO TO 57
56          ITEX=0
            GO TO 44
57          CONTINUE
C           TURN OFF "OB" FLAG IN CONVEX RIGHT ANGLE BOUNDARIES.
C
            LOGICAL TA,TB,TC,TD
            DO 59 L=2,LMAXZ
            KTT=L*KMAX
            DO 59 K=2,KMAXZ
            KT=KTT+K
            KM=KT-KMAX
            KB=KM-KMAX
            TA=(((M(KB).AND.OB).EQ.OB).AND.((M(KM-1).AND.OB).EQ.OB)
     *      .AND.((M(KT).AND.COR).NE.COR).AND.((M(KM+1).AND.COR).NE.COR))
            TB=(((M(KB).AND.OB).EQ.OB).AND.((M(KM+1).AND.OB).EQ.OB)
     *      .AND.((M(KM-1).AND.COR).NE.COR).AND.((M(KT).AND.COR).NE.COR))
            TC=(((M(KM+1).AND.OB).EQ.OB).AND.((M(KT).AND.OB).EQ.OB)
     *      .AND.((M(KM-1).AND.COR).NE.COR).AND.((M(KB).AND.COR).NE.COR))
            TD=(((M(KM-1).AND.OB).EQ.OB).AND.((M(KT).AND.OB).EQ.OB)
     *      .AND.((M(KM+1).AND.COR).NE.COR).AND.((M(KB).AND.COR).NE.COR))
            TEST=((M(KM).AND.OB).EQ.OB).AND.(TA.OR.TB.OR.TC.OR.TD)
            IF(TEST) GO TO 58
            GO TO 59
58          M(KM)=(M(KM).AND.MASK2)
59          CONTINUE
            TYPE 1012
            TYPE 1009
1012        FORMAT(1H ,'ICRT,CRTRA,CRTRB,CRTZA,CRTZB,XMAX,YMAX')
            READ(NDEV1,60)ICRT,CRTRA,CRTRB,CRTZA,CRTZB,XMAX,YMAX
            TYPE 1013
            TYPE 1009
1013        FORMAT(1H ,'KDMN,KDMX,LDMN,LDMX')
            READ(NDEV1,61)KDMN,KDMX,LDMN,LDMX
60          FORMAT(I,6F)
61          FORMAT(4I)
            ITEST=0
            PGAS=PGAS2
            GASV=C.
            CALL REFLAG
            DO 65 L=2,LMAXZ
            KL=(L-1)*KMAX+1
            KR=L*KMAX
            IF((M(KL).AND.COR).EQ.COR)GO TO 63
            M(KL)=(M(KL).OR.BND)
63          IF((M(KR).AND.COR).EQ.COR) GO TO 65
            M(KR)=(M(KR).OR.BND)
65          CONTINUE
            DO 69 K=1,KMAX
            KT=K+LMAXZ*KMAX
            KTZ=K+(LMAXZ-1)*KMAX
            KB=K+KMAX
            IF((M(K).AND.COR).EQ.COR) GO TO 67
```

```
        M(K)=(M(K).OR.BND)
67      IF((M(KT).AND.COR).EQ.COR) GO TO 69
        M(KT)=(M(KT).OR.BND)
69      CONTINUE
        IOZ=1
        NTAL=C
        RETURN
        END
```

```
      SUBROUTINE GENB
      COMMON NVAC,NGEN,UAC,VAC,TM1,TM2,TM3
      COMMON NCYCLE,NSTOP,NEDTM,NEDIT,OPE
      COMMON TIME,EDTIM,EDDT,NPIT
      COMMON BETA,EPS2,DT,VMAX,UMAX,RELAX,CUT
      COMMON SMIN,EPS1,NBMAX,UBTO,VBTO,UBND,VBND
      COMMON UM,MU,RHOA,GR,GZ,G,ISEC
      COMMON VIN,UIN,DKP,DLP,NBP,DDR,DDZ
      COMMON NEXP,NEXPP,NPART,NDIV
      COMMON NGRID,KMAX,LMAX,KMAXZ,LMAXZ,KMAXZZ,LMAXZZ
      COMMON KDMN,LDMN,KDMX,LDMX,MESS(7)
      COMMON ICRT,XMAX,YMAX,CRTRA,CRTRB,CRTZA,CRTZB
      COMMON ITEST,IOZ,IZ,GAMA,PGAS,PGASZ,PAMB,GASV,GASVZ
      COMMON NF,NG,NIT,H,XG,HH,HV,GG,FUDGE,ITAL,CRAX,DELZ
      COMMON BPX(300),PTX(300),RMP(300),RNP(300),XB(300)
      COMMON BPY(300),PTY(300),ZMP(300),ZNP(300),YB(300)
      COMMON DS(300),IBP(300)
      COMMON R(150),Z(150),RB(150),ZB(150)
      COMMON DRB(150),DZB(150)
      COMMON M(2500)
      COMMON RP1(5000),RP2(5000)
      COMMON UAVG(2500),VAVG(2500)
      COMMON P(2500),U(2500),ETA(2500),V(2500),PSI(2500)
      COMMON DNORX(2500),DNORY(2500),PNORX(2500),PNORY(2500)
      COMMON NPRTA(2500),NPRTB(2500),MPRTA(2500),MPRTB(2500)
      COMMON SNC(2500),DR,DZ
      COMMON NBC(300),IPX(300)
      COMMON NDEV1,NDEV2
      COMMON/FLAG1/FLAG1
      REAL MU
      INTEGER AND,OR,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     * FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,ARB
      DATA INTRF,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     * FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,ARB/1,2,4,8,16,32,
     * 64,128,256,512,1024,2048,4096,8192,16384,32768/
      DATA MASK1,MASK2,MASK3,MASK4,MASK5,MASK6,
     * MASK7,MASK8/0777777777757,0777777773777,
     * 0777777677777,0777777777773,0777777777767,
     * 0777777737777,0777777757777,0777777767777/
      DOUBLE PRECISION UMAX,VMAX
      DOUBLE PRECISION U,V,PSI,ETA,P
      PI=3.1415926
      DEPSX=.05*DR
      DEPSY=.05*DZ
1     N=1
      TYPE 1001
1001  FORMAT(1H ,'XB,YB,NSEQ',$)
      TYPE 2001
2001  FORMAT(1H )
2     READ(NDEV1,3) XB(N),YB(N),NSEQ
3     FORMAT(2F,1)
      IF(NSEQ)88,4,5
4     N=N+1
      GO TO 2
5     NBMAX=N-1
      ISEC=0
      DO 32 I=1,NBMAX
```

```
          IF(XB(I+1)-XB(I))10,14,6
6         K1=(XB(I)+.000001)/DR+2
          A=(YB(I+1)-YB(I))/(XB(I+1)-XB(I))
          KJK=1
          MM=0
          K2=KMAX
          B=YB(I)-A*XB(I)
          DO 8 K=K1,K2,KDK
          IF(RB(K)-XB(I+1)-0.000001)7,7,9
7         MM=MM+1
          RMP(MM)=RB(K)
          ZMP(MM)=A*RMP(MM)+B
8         CONTINUE
9         KLINE=MM
          GO TO 15
10        K1=(XB(I)-.000001)/DR+1
          A=(YB(I+1)-YB(I))/(XB(I+1)-XB(I))
          K2=1
          B=YB(I)-A*XB(I)
          KDK=-1
          MM=0
          DO 12 K=K1,K2,KDK
          IF(RB(K)-XB(I+1)+.000001) 13,11,11
11        MM=MM+1
          RMP(MM)=RB(K)
12        ZMP(MM)=A*RMP(MM)+B
13        KLINE=MM
          GO TO 15
14        KLINE=0
15        CONTINUE
          IF(YB(I+1)-YB(I))20,24,16
16        L1=(YB(I)+.000001)/DZ+2
          A=(XB(I+1)-XB(I))/(YB(I+1)-YB(I))
          L2=LMAX
          B=XB(I)-A*YB(I)
          LDL=1
          N=0
          DO 18 L=L1,L2,LDL
          IF(ZB(L)-YB(I+1)-.000001)17,17,19
17        N=N+1
          ZNP(N)=ZB(L)
18        RNP(N)=A*ZNP(N)+B
19        LLINE=N
          GO TO 25
20        L1=(YB(I)-.000001)/DZ+1
          A=(XB(I+1)-XB(I))/(YB(I+1)-YB(I))
          L2=1
          B=XB(I)-A*YB(I)
          LDL=-1
          N=0
          DO 22 L=L1,L2,LDL
          IF(ZB(L)-YB(I+1)+.000001)23,21,21
21        N=N+1
          ZNP(N)=ZB(L)
22        RNP(N)=ZNP(N)*A+B
23        LLINE=N
          GO TO 25
```

```
24        LLINE=0
25        CONTINUE
          DO 26 J=1,LLINE
          JJ=J+KLINE
          RMP(JJ)=RNP(J)
26        ZMP(JJ)=ZNP(J)
          JMAX=KLINE+LLINE
          DO 27 J=1,JMAX
27        DS(J)=(RMP(J)-XB(I))**2+(ZMP(J)-YB(I))**2
          DO 30 N=1,JMAX
          TEST=10.0**5
          MTRANS=0
          DO 29 MM=1,JMAX
          IF(DS(MM)-TEST)28,28,29
28        TEST=DS(MM)
          MTRANS=MM
29        CONTINUE
          RNP(N)=RMP(MTRANS)
          ZNP(N)=ZMP(MTRANS)
          DS(MTRANS)=10.0**7
30        CONTINUE
          J1=ISEC+1
          J2=ISEC+JMAX
          N=0
          DO 31 J=J1,J2
          N=N+1
          PTX(J)=RNP(N)
          PTY(J)=ZNP(N)
31        CONTINUE
          ISEC=ISEC+JMAX
32        CONTINUE
          I=1
33        I=I+1
34        IF(ABS(PTX(I)-PTX(I-1))-DEPSX)35,35,38
35        IF(ABS(PTY(I)-PTY(I-1))-DEPSY)36,36,38
36        ISEC=ISEC-1
          DO 37 J=I,ISEC
          PTX(J)=PTX(J+1)
          PTY(J)=PTY(J+1)
37        CONTINUE
          IF(I-ISEC)34,34,39
38        IF(I-ISEC)33,39,39
39        CONTINUE
          ISEC2=ISEC-1
          DEP=(PTX(ISEC)-PTX(ISEC2))**2+(PTY(ISEC)-PTY(ISEC2))**2
          DEP=SQRT(DEP)
          IF(DEP-.2*DR)41,42,42
41        ISEC=ISEC2
42        CONTINUE
          DEP=(PTX(2)-PTX(1))**2+(PTY(2)-PTY(1))**2
          DEP=SQRT(DEP)
          IF(DEP-.2*DR)43,44,44
43        I=1
          GO TO 45
44        I=0
45        I=I+1
          K=(.5*(PTX(I+1)+PTX(I)))/DR+2
```

```
          L=(1.000001*PTY(I))/DZ+1
          IF((PTY(I).EQ.PTY(I+1)).AND.(PTY(I).EQ.ZB(L)))GO TO 46
          GO TO 49

46        IF(PTX(I+1)-PTX(I))48,48,47
47        KM=L*KMAX+K
          KB=KM-KMAX
          DNORX(KM)=0.
          DNORY(KM)=1.
          PNORX(KM)=.5*(PTX(I)+PTX(I+1))
          PNORY(KM)=PTY(I)
          M(KM)=(M(KM).OR.OB)
          M(KB)=(M(KB).OR.COR)
          GO TO 53
48        KM=(L-1)*KMAX+K
          KT=KM+KMAX
          DNORX(KM)=0.
          DNORY(KM)=-1.
          PNORX(KM)=.5*(PTX(I)+PTX(I+1))
          PNORY(KM)=PTY(I)
          M(KT)=(M(KT).OR.COR)
          M(KM)=(M(KM).OR.OB)
          GO TO 53
49        L=(.5*(PTY(I+1)+PTY(I)))/DZ+2
          K=(1.000001*PTX(I))/DR+1
          IF((PTX(I).EQ.PTX(I+1)).AND.(PTX(I).EQ.RB(K)))GO TO 50
          GO TO 40
50        IF(PTY(I+1)-PTY(I))52,52,51
51        KM=(L-1)*KMAX+K-1
          DNORX(KM)=-1.
          DNORY(KM)=0.
          PNORX(KM)=PTX(I)
          PNORY(KM)=.5*(PTY(I+1)+PTY(I))
          M(KM)=(M(KM).OR.OB)
          M(KM+1)=(M(KM+1).OR.COR)
          GO TO 53
52        KM=(L-1)*KMAX+K
          DNORX(KM)=1.
          DNORY(KM)=0.
          PNORX(KM)=PTX(I)
          PNORY(KM)=.5*(PTY(I+1)+PTY(I))
          M(KM-1)=(M(KM-1).OR.COR)
          M(KM)=(M(KM).OR.OB)
53        CONTINUE
          GO TO 83
40        CONTINUE
          DX=PTX(I+1)-PTX(I)
          XBAR=.5*(PTX(I)+PTX(I+1))
          DY=PTY(I+1)-PTY(I)
          YBAR=.5*(PTY(I)+PTY(I+1))
          K=XBAR/DR+1
          L=YBAR/DZ+1
          SUM=-YBAR*DX
          IF(PTX(I+1)-RB(K))57,54,57
54        IF(PTY(I)-ZB(L))55,56,55
55        SUM=SUM-ZB(L)*DR-(PTX(I)-RB(K+1))*ZB(L+1)
          GO TO 64
```

```
56      SUM=SUM-(PTX(I)-RB(K))*ZB(L)
        GO TO 64
57      IF(PTY(I+1)-ZB(L))59,58,59
58      SUM=SUM-(RB(K+1)-PTX(I+1))*ZB(L)-(PTX(I)-RB(K+1))*ZB(L+1)
        GO TO 64
59      IF(PTX(I+1)-RB(K+1))63,60,63
60      IF(PTY(I)-ZB(L+1))61,62,61
61      SUM=SUM+ZB(L+1)*DR-(PTX(I)-RB(K))*ZB(L)
        GO TO 64
62      SUM=SUM-(PTX(I)-RB(K+1))*ZB(L+1)
        GO TO 64
63      SUM=SUM-(RB(K)-PTX(I+1))*ZB(L+1)-(PTX(I)-RB(K))*ZB(L)
64      CONTINUE
        KPRM=K+1
        LPRM=L+1
        IF(SUM-SMIN)65,79,79
65      IF(ABS(DY)-ABS(DX))69,69,66
66      IF(DY)67,67,68
67      KPRM=K+2
        GO TO 72
68      KPRM=K
        GO TO 72
69      IF(DX)70,70,71
70      LPRM=L
        GO TO 72
71      LPRM=L+2
72      CONTINUE
        KKM=L*KMAX+K+1
        M(KKM)=(M(KKM).OR.COR)
        XAVG=.5*(PTX(I+2)+PTX(I+1))
        YAVG=.5*(PTY(I+2)+PTY(I+1))
        KAVG=XAVG/DR+2
        LAVG=YAVG/DZ+2
        IF((KPRM.EQ.KAVG).AND.(LPRM.EQ.LAVG)) GO TO 73
        GO TO 75
73      ISEC=ISEC-1
        I2=I+1
        DO 74 J=I2,ISEC
        PTX(J)=PTX(J+1)
        PTY(J)=PTY(J+1)
74      CONTINUE
        GO TO 78
75      XAVG=.5*(PTX(I)+PTX(I-1))
        YAVG=.5*(PTY(I)+PTY(I-1))
        KAVG=XAVG/DR+2
        LAVG=YAVG/DZ+2
        KCEL=(LAVG-1)*KMAX+KAVG
        KCEL=KCEL+NPRTB(KCEL)
        KMPT=(LPRM-1)*KMAX+KPRM
        IF(KMPT.EQ.KCEL) GO TO 76
        GO TO 79
76      ISEC=ISEC-1
        I2=I
        I=I-1
        DO 77 J=I2,ISEC
        PTX(J)=PTX(J+1)
        PTY(J)=PTY(J+1)
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77          CONTINUE
76          CONTINUE
            XBAR=.5*(PTX(I+1)+PTX(I))
            YBAR=.5*(PTY(I+1)+PTY(I))
            DX=PTX(I+1)-PTX(I)
            DY=PTY(I+1)-PTY(I)
79          CONTINUE
            FMAG=SQRT(DX**2+DY**2)
            IF(FMAG)80,80,82
80          TYPE 81
81          FORMAT(1H ,'FMAG=0')
            CALL EXIT
82          CONTINUE
            KM=(LPRM-1)*KMAX+KPRM
            KAVG=XBAR/DR+2
            LAVG=YBAR/DZ+2
            KBAR=(LAVG-1)*KMAX+KAVG
            KSTOR=KM-KBAR
            NPRTB(KBAR)=KSTOR
            M(PRM)=(M(KM).OR.OB)
            DNORX(PM)=-DY/FMAG
            DNORY(KM)=DX/FMAG
            PNORX(KM)=XBAR
            PNORY(KM)=YBAR
83          IF(I-ISEC+1)45,84,84
84          CONTINUE
            DO 87 H=1,NPART
            XR=RP1(H)
            XZ=RP2(H)
            L=XZ/DZ+2
            K=XR/DR+2
            KBAR=(L-1)*KMAX+K
            KSTOR=(NPRTB(KBAR))
            KM=KBAR+KSTOR
            IF((DNORX(KM).NE.0).OR.(DNORY(KM).NE.0)) GO TO 85
            GO TO 87
85          PDOTN=(XR-PNORX(KM))*DNORX(KM)+(XZ-PNORY(KM))*DNORY(KM)
            IF(PDOTN-EPS1)86,86,87
86          M(KM)=(M(KM).OR.ARB)
87          CONTINUE
5500        FORMAT(1H ,2F)
            IF(NSEG-2)88,1,1
88          CONTINUE
5501        FORMAT(1H ,3F)
5502        FORMAT(1H ,4F)
            RETURN
            END
```

```
      SUBROUTINE REFLAG
      COMMON NVAC,NGEN,UAC,VAC,TM1,TM2,TM3
      COMMON NCYCLE,NSTOP,NEDTM,NEDIT,OPE
      COMMON TIME,EDTIM,EDDT,NPIT
      COMMON BETA,EPS2,DT,VMAX,UMAX,RELAX,CUT
      COMMON SMIN,EPS1,NGMAX,UBTO,VBTO,UBND,VBND
      COMMON UM,MU,RHOA,GR,GZ,G,ISEC
      COMMON VIN,UIN,DKP,DLP,NBP,DDR,DDZ
      COMMON NEXP,NEXPP,NPAR1,NDIV
      COMMON NGRID,KMAX,LMAX,KMAXZ,LMAXZ,KMAXZZ,LMAXZZ
      COMMON KDMN,LDMN,KDMX,LDMX,MESS(7)
      COMMON ICRT,XMAX,YMAX,CRTRA,CRTRB,CRTZA,CRTZB
      COMMON ITEST,IOZ,IZ,GAMA,PGAS,PGASZ,PAMB,GASV,GASVZ
      COMMON NF,NG,NII,H,XG,HH,HV,GG,FUDGE,NTAL,CRAX,DELZ
      COMMON BPX(300),PTX(300),RMP(300),RNP(300),XB(300)
      COMMON BPY(300),PTY(300),ZMP(300),ZNP(300),YB(300)
      COMMON DS(300),IBP(300)
      COMMON R(150),Z(150),RB(150),ZB(150)
      COMMON DRB(150),DZB(150)
      COMMON M(2500)
      COMMON RP1(5000),RP2(5000)
      COMMON UAVG(2500),VAVG(2500)
      COMMON P(2500),U(2500),ETA(2500),V(2500),PSI(2500)
      COMMON DNORX(2500),DNORY(2500),PNORX(2500),PNORY(2500)
      COMMON NPRTA(2500),NPRTB(2500),MPRTA(2500),MPRTB(2500)
      COMMON SNC(2500),DR,DZ
      COMMON NBC(300),IPX(300)
      COMMON NDEV1,NDEV2
      COMMON/FLAG1/FLAG1
      REAL MU
      INTEGER AND,OR,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     * FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,ARB
      DATA INTRF,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     * FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,ARB/1,2,4,8,16,32,
     * 64,128,256,512,1024,2048,4096,8192,16384,32768/
      DATA MASK1,MASK2,MASK3,MASK4,MASK5,MASK6,
     * MASK7,MASK8/0777777777757,0777777773777,
     * 0777777677777,0777777777773,0777777777767,
     * 0777777737777,0777777757777,0777777767777/
      DOUBLE PRECISION UMAX,VMAX
      DOUBLE PRECISION U,V,PSI,ETA,P
      PI=3.1415926
      LOGICAL TA,TB,TC,TV,TH,TEST
      LOGICAL ANI,AA,AB,AC,AD
1     DO 23 L=2,LMAXZ
      KMM=L*KMAX
      DO 23 K=2,KMAXZ
      KT=K+KMM
      KM=KT-KMAX
      KB=KM-KMAX
      IF((M(KM).AND.SUR).EQ.SUR) GO TO 2
      GO TO 13
2     IF(MPRTA(KM))23,3,23
3     IF((M(KM).AND.OB).EQ.OB) GO TO 4
      GO TO 5
4     TEST=((M(KM+1).AND.COR).EQ.COR).OR.((M(KM+1).AND.SUR).EQ.SUR)
     * .OR.((M(KM+1).AND.FULL).EQ.FULL).OR.((M(KM+1).AND.BND).EQ.BND)
```

```
      TEST=TEST.AND.(((M(KM-1).AND.COR).EQ.COR).OR.
     *  ((M(KM-1).AND.SUR).EQ.SUR).OR.((M(KM-1).AND.FULL).EQ.FULL)
     *  .OR.((M(KM-1).AND.BND).EQ.BND))
      TEST=TEST.AND.(((M(KT).AND.COR).EQ.COR).OR.
     *  ((M(KT).AND.SUR).EQ.SUR).OR.((M(KT).AND.FULL).EQ.FULL)
     *  .OR.((M(KT).AND.BND).EQ.BND))
      TEST=TEST.AND.(((M(KB).AND.COR).EQ.COR).OR.
     *  ((M(KB).AND.SUR).EQ.SUR).OR.((M(KB).AND.FULL).EQ.FULL)
     *  .OR.((M(KB).AND.BND).EQ.BND))
      IF(TEST) GO TO 23
    5 M(KM)=(M(KM).OR.EMP)
      M(KM)=(M(KM).AND.MASK3)
      M(KM)=(M(KM).AND.MASK4)
      P(KM)=0.0
      IF(((M(KM+1)).AND.EMP).EQ.EMP) GO TO 6
      GO TO 7
    6 CONTINUE
      U(KM)=0.0
    7 IF(((M(KM-1).AND.EMP).EQ.EMP) U(KM-1)=0.0
    9 IF(((M(KT).AND.EMP).EQ.EMP) V(KM)=0.0
   11 IF(((M(KB).AND.EMP).EQ.EMP) V(KB)=0.0
      GO TO 23
   13 IF(((M(KM).AND.EMP).EQ.EMP) GO TO 14
      GO TO 23
   14 P(KM)=0.0
      NNN=NPRTA(KM)
      IF(NNN)15,23,15
   15 M(KM)=(M(KM).OR.SUR)
      M(KM)=(M(KM).AND.MASK1)
      J=KM
      VBAR=VAVG(J)
      VBAR=VBAR/NNN
      UBAR=UAVG(J)
      UBAR=UBAR/NNN
      IF((((M(KM+1).AND.EMP).EQ.EMP).OR.((M(KM+1).AND.OUT).EQ.OUT))
     *  GO TO 16
      GO TO 17
   16 U(KM)=UBAR
   17 IF((((M(KM-1).AND.EMP).EQ.EMP).OR.((M(KM-1).AND.OUT).EQ.OUT))
     *  U(KM-1)=UBAR
   19 IF((((M(KT).AND.EMP).EQ.EMP).OR.((M(KT).AND.OUT).EQ.OUT))
     *  V(KM)=VBAR
   21 IF((((M(KB).AND.EMP).EQ.EMP).OR.((M(KB).AND.OUT).EQ.OUT))
     *  V(KB)=VBAR
   23 CONTINUE
      DO 47 L=2,LMAX2
      KMM=L*KMAX
      DO 47 K=2,KMAX2
      KT=K+KMM
      KM=KT-KMAX
      KB=KM-KMAX
      IF(NPRTA(KM)) 24,47,24
   24 IF(((M(KM).AND.FULL).EQ.FULL) GO TO 25
      GO TO 30
   25 IF(((M(KM+1).AND.EMP).EQ.EMP) GO TO 29
      GO TO 26
   26 IF(((M(KM-1).AND.EMP).EQ.EMP) GO TO 29
```

```
            IF((M(KT).AND.EMP).EQ.EMP) GO TO 29
            IF((M(KB).AND.EMP).EQ.EMP) GO TO 29
            GO TO 47
29          M(KM)=(M(KM).OR.SUR)
            M(KM)=(M(KM).AND.MASK5)
            P(KM)=0.0
            GO TO 47
30          IF((M(KM).AND.OB).EQ.OB) GO TO 47
            IF((M(KM).AND.SUR).EQ.SUR) GO TO 32
            GO TO 47
32          SGP=0.0
            P(KM)=0.0
            N=0
            IF((M(KM+1).AND.EMP).EQ.EMP) GO TO 47
            IF((M(KM+1).AND.FULL).EQ.FULL) GO TO 34
            GO TO 35
34          SGP=SGP+P(KM+1)
            N=N+1
35          IF((M(KM-1).AND.EMP).EQ.EMP) GO TO 47
            IF((M(KM-1).AND.FULL).EQ.FULL) GO TO 37
            GO TO 38
37          SGP=SGP+P(KM-1)
            N=N+1
38          IF((M(KT).AND.EMP).EQ.EMP) GO TO 47
            IF((M(KT).AND.FULL).EQ.FULL) GO TO 40
            GO TO 41
40          SGP=SGP+P(KT)
            N=N+1
41          IF((M(KB).AND.EMP).EQ.EMP) GO TO 47
            IF((M(KB).AND.FULL).EQ.FULL) GO TO 43
            GO TO 44
43          SGP=SGP+P(KB)
            N=N+1
44          M(KM)=(M(KM).OR.FULL)
            M(KM)=(M(KM).AND.MASK6)
            M(KM)=(M(KM).AND.MASK4)
            IF(N)45,45,46
45          P(KM)=0.0
            GO TO 47
46          P(KM)=SGP/N
47          CONTINUE
            DO 68 L=2,LMAXZ
            KTT=L*KMAX
            DO 68 K=2,KMAXZ
            KT=KTT+K
            KM=KT-KMAX
            KB=KM-KMAX
            IF((M(KM).AND.OB).EQ.OB) GO TO 48
            GO TO 68
48          AA=((M(KM).AND.OK).EQ.OK)
            TA=((M(KM+1).AND.OB).EQ.OB).AND.((M(KM+1).AND.EMP).EQ.EMP)
            TB=((M(KT).AND.OB).EQ.OB).AND.((M(KT).AND.EMP).EQ.EMP)
            TC=((M(KM-1).AND.OB).EQ.OB).AND.((M(KM-1).AND.EMP).EQ.EMP)
            TV=((M(KB).AND.OB).EQ.OB).AND.((M(KB).AND.EMP).EQ.EMP)
            TEST=TA.OR.TB.OR.TC.OR.TV
            M(KM)=(M(KM).AND.MASK7)
            IF(((M(KM).AND.OB).EQ.OB).AND.((M(KM).AND.ARB).EQ.ARB).AND.
```

```
     *      (.NOT.TEST)) M(KM)=(M(KM).OR.OK)
            TEST=.FALSE.
            IF(DNORX(KM))49,51,50
49          IF((M(KM-1).AND.EMP).EQ.EMP) TEST=.TRUE.
            GO TO 51
50          IF((M(KM+1).AND.EMP).EQ.EMP) TEST=.TRUE.
51          IF(DNORY(KM))52,54,53
52          IF((M(KB).AND.EMP).EQ.EMP) TEST=TEST.OR..TRUE.
            GO TO 54
53          IF((M(KT).AND.EMP).EQ.EMP) TEST=TEST.OR..TRUE.
54          IF(TEST.AND.((M(KM).AND.OK).EQ.OK)) M(KM)=(M(KM).AND.MASK7)
            IF((M(KM).AND.OK).EQ.OK) GO TO 56
            P(KM)=P.
            GO TO 68
56          TEST=(AA.EQ..FALSE.).AND.((M(KM).AND.OK).EQ.OK)
            IF(TEST) GO TO 57
            GO TO 68
57          N=0
            SP=0.
            IF(((M(KT).AND.OK).EQ.OK).OR.((M(KT).AND.FULL).EQ.FULL))
     *      GO TO 58
            GO TO 59
58          SP=SP+P(KT)
            N=N+1
59          IF(((M(KB).AND.OK).EQ.OK).OR.((M(KB).AND.FULL).EQ.FULL))
     *      GO TO 60
            GO TO 61
60          SP=SP+P(KB)
            N=N+1
61          IF(((M(KM+1).AND.OK).EQ.OK).OR.((M(KM+1).AND.FULL).EQ.FULL))
     *      GO TO 62
            GO TO 63
62          SP=SP+P(KM+1)
            N=N+1
63          IF(((M(KM-1).AND.OK).EQ.OK).OR.((M(KM-1).AND.FULL).EQ.FULL))
     *      GO TO 64
            GO TO 65
64          SP=SP+P(KM-1)
            N=N+1
65          IF(N)68,68,66
66          P(KM)=SP/N
68          CONTINUE
            CALL VELU5
            DO 71 L=2,LMAX2
            KMM=(L-1)*KMAX
            DO 71 K=2,KMAX2
            KM=K+KMM
            IF(((M(KM).AND.EMP).EQ.EMP).OR.((M(KM).AND.SUR).EQ.SUR))
     *      GO TO 69
            GO TO 71
69          IF((M(KM).AND.ARB).EQ.ARB) GO TO 71
            P(KM)=PAMB
71          CONTINUE
            RETURN
            END
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```
      SUBROUTINE EDIT
      COMMON NVAC,NGEN,UAC,VAC,TM1,TM2,TM3
      COMMON NCYCLE,NSTOP,NEDTM,NEDII,OPE
      COMMON TIME,EDTIM,EDDI,NPIT
      COMMON BETA,EPS2,DT,VMAX,UMAX,RELAX,CUT
      COMMON SMIN,EPS1,NBMAX,UBTO,VBTO,UBND,VBND
      COMMON UM,MU,RHOA,GR,GZ,G,ISEC
      COMMON VIN,UIN,DKP,DLP,NBP,DDR,DDZ
      COMMON NEXP,NEXPP,NPART,NDIV
      COMMON NGRID,KMAX,LMAX,KMAXZ,LMAXZ,KMAXZZ,LMAXZZ
      COMMON KDMN,LDMN,KDMX,LDMX,MESS(7)
      COMMON ICRT,XMAX,YMAX,CRTRA,CRTRB,CRTZA,CRTZB
      COMMON ITEST,IOZ,IZ,GAMA,PGAS,PGASZ,PAMB,GASV,GASVZ
      COMMON NF,NG,NII,II,XG,HH,HV,GG,FUDGE,NTAL,CRAX,DELZ
      COMMON BPX(300),PTX(300),RMP(300),RNP(300),XB(300)
      COMMON BPY(300),PTY(300),ZMP(300),ZNP(300),YB(300)
      COMMON DS(300),ILP(300)
      COMMON R(150),Z(150),RB(150),ZB(150)
      COMMON DRB(150),DZB(150)
      COMMON M(2500)
      COMMON RP1(5000),RP2(5000)
      COMMON UAVG(2500),VAVG(2500)
      COMMON P(2500),U(2500),ETA(2500),V(2500),PSI(2500)
      COMMON DNORX(2500),DNORY(2500),PNORX(2500),PNORY(2500)
      COMMON NPRTA(2500),NPRIB(2500),MPRTA(2500),MPRTB(2500)
      COMMON SNC(2500),DR,DZ
      COMMON NBC(300),IPX(300)
      COMMON NDEV1,NDEV2
      COMMON/FLAG1/FLAG1
      REAL MU
      INTEGER AND,OR,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     * FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,ARB
      DATA INTRF,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     * FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,ARB/1,2,4,8,16,32,
     * 64,128,256,512,1024,2048,4096,8192,16384,32768/
      DATA MASK1,MASK2,MASK3,MASK4,MASK5,MASK6,
     * MASK7,MASK8/07777777777757,07777777773777,
     * 07777776777777,07777777777773,07777777777767,
     * 07777777737777,07777777757777,07777777767777/
      DOUBLE PRECISION U,V,PSI,ETA,P
      DOUBLE PRECISION VMAX,UMAX
      PI=3.1415926
      WRITE(22,1)
    1 FORMAT(1H ,'EDIT')
    2 FORMAT(1H ,'L=',I5,5X,'K,ETA,PSI,U,V,P,X OR R,UPART,VPART')
    4 FORMAT(1H ,'CYCLE',I8,' TIME',E,' DT',E,' NPART',
     * I10,' PAMB',F)
    5 WRITE(22,4)NCYCLE,TIME,DT,NPART,PAMB
      WRITE(22,7)RHOA,MU
    7 FORMAT(1H ,5X,'RHOA=',E,' MU=',E)
      WRITE(22,8)
    8 FORMAT(1H ,'SURFACE PARTICLES')
      MM=0
      DO 14 N=1,NPART
      XX=RP1(N)
      YY=RP2(N)
      K=XX/DR+2
```

```
          L=YY/DZ+2
          KM=K+(L-1)*KMAX
          IF((M(KM).AND.SUR).EQ.SUR) GO TO 9
          GO TO 14
9         MM=MM+1
          GO TO (10,11,12),MM
10        X1=XX
          Y1=YY
          GO TO 14
11        X2=XX
          Y2=YY
          GO TO 14
12        X3=XX
          Y3=YY
          MM=0
13        FORMAT(1H ,9X,2E,2X,2E,2X,2E)
          WRITE(22,13)X1,Y1,X2,Y2,X3,Y3
14        CONTINUE
          DO 27 L=LDMN,LDMX
          KTT=(L-1)*KMAX
          WRITE(22,15)(MESS(I),I=1,7)
15        FORMAT(1H ,7A5)
          WRITE(22,16)Z(L),NCYCLE,TIME,MU,RHOA
16        FORMAT(1H ,'Z=',E,' CYCLE=',I,' TIME=',E,' MU=',
     *    E,'RHO=',E)
          WRITE(22,2)L
          DO 21 K=KDMN,KDMX
          KP=K+KTT
          UPART=UAVG(KP)
          VPART=VAVG(KP)
          NP=NPRTA(KP)
          IF(NP)17,17,18
17        UPART=0.
          VPART=0.
          GO TO 19
18        UPART=UPART/NP
          VPART=VPART/NP
19        TEST=(U(KP).NE.0).OR.(V(KP).NE.0)
          IF(TEST) GO TO 20
          GO TO 21
20        CONTINUE
          WRITE(22,3)K,ETA(KP),PSI(KP),U(KP),V(KP),P(KP),R(K),
     *    UPART,VPART
3         FORMAT(1H ,I4,8E15.8)
21        CONTINUE
          IF(OFE.GT.0) GO TO 22
          GO TO 27
22        WRITE(22,23)L
23        FORMAT(1H ,'L=',I5,'K,FULL,SUR,EMP,OB,OK,ARB,COR,BND,IN,OUT,GAS,
     *    EMPBND,SNC,NPT,KMPR,DNORX,DNORY,PNORX,PNORY,UBND,VBND')
          DO 26 K=KDMN,KDMX
          KM=K+KTT
          TEST=(NPRTA(KM).NE.0).OR.(AND(M(KM),COR).EQ.COR)
     *    .OR.(AND(M(KM),OB).EQ.OB).OR.(AND(M(KM),SUR).EQ.SUR)
     *    .OR.(AND(M(KM),FULL).EQ.FULL).OR.(AND(M(KM),BND).EQ.BND)
     *    .OR.(AND(M(KM),IN).EQ.IN).OR.(AND(M(KM),OUT).EQ.OUT)
     *    .OR.(.NOT.(AND(M(KM),EMP).EQ.EMP))
```

```
         IF(TEST) GO TO 24
         GO TO 26
24       MA=0
         IF(AND(M(KM),FULL).EQ.FULL) MA=1
         MB=0
         IF(AND(M(KM),SUR).EQ.SUR) MB=1
         MC=0
         IF(AND(M(KM),EMP).EQ.EMP) MC=1
         MD=0
         IF(AND(M(KM),OB).EQ.OB) MD=1
         ME=0
         IF(AND(M(KM),OK).EQ.OK) ME=1
         MF=0
         IF(AND(M(KM),ARB).EQ.ARB) MF=1
         MG=0
         IF(AND(M(KM),COR).EQ.COR) MG=1
         MH=0
         IF(AND(M(KM),BND).EQ.BND) MH=1
         MI=0
         IF(AND(M(KM),IN).EQ.IN) MI=1
         MJ=0
         IF(AND(M(KM),OUT).EQ.OUT) MJ=1
         MK=0
         IF(AND(M(KM),GAS).EQ.GAS) MK=1
         ML=0
         IF(AND(M(KM),EMPBND).EQ.EMPBND) ML=1
         MM=SNC(KM)
         NA=NPRTA(KM)
         NB=NPRTB(KM)
         WRITE(22,25)K,MA,MB,MC,MD,ME,MF,MG,MH,MI,MJ,MK,ML,
       * MM,NA,NB,DNORX(KM),DNORY(KM),PNORX(KM),PNORY(KM)
25       FORMAT(1H ,I5,1X,3I1,1X,4I1,1X,3I1,1X,3I1,1X,2I3,
       * 4F)
26       CONTINUE
27       CONTINUE
         TYPE 28,NCYCLE
         WRITE(22,28)NCYCLE
28       FORMAT(1H ,'EDIT COMPLETE FOR CYCLE',I4)
         END FILE 22
         RETURN
         END
```

APPENDIX III

THE COMPUTATIONAL PROGRAM

Routine Name	Function
MAIN	Read in data from initialization program, compute ETA and PSI values, controls other computation.
PRES	Pressure Iteration
VEL	Velocity computation
VEL55	Free surface velocities
NOSLIP	Takes care of no-slip boundary condition

```
      COMMON NVAC,NGEN,UAC,VAC,TM1,TM2,TM3
      COMMON NCYCLE,NSTOP,NEDTM,NEDIT,OPE
      COMMON TIME,EDTIM,EDUT,NPIT,NITER
      COMMON BETA,EPS2,DT,VMAX,UMAX,RELAX,CUT
      COMMON SMIN,EPS1,HBMAX,UBTO,VBTO,UBND,VBND
      COMMON UM,MU,RHOA,GR,GZ,G,ISEC
      COMMON VIN,UIN,DKF,DLP,NBP,DDR,DDZ
      COMMON NEXP,NEXPP,NPART,NDIV
      COMMON NGRID,KMAX,LMAX,KMAXZ,LMAXZ,KMAXZZ,LMAXZZ
      COMMON KDMN,LDMN,KDMX,LDMX,MESS(7)
      COMMON ICRT,XMAX,YMAX,CRTRA,CRTRB,CRTZA,CRTZB
      COMMON ITEST,IOZ,IZ,GAMA,PGAS,PGASZ,PAMB,GASV,GASVZ
      COMMON NF,NG,NIT,H,XG,HH,HV,GG,FUDGE,NTAL,CRAX,DELZ
      COMMON R(150),Z(150),RB(150),ZB(150)
      COMMON DRB(150),DZB(150)
      COMMON M(2500)
      COMMON P(2500),U(2500),FTA(2500),V(2500),PSI(2500)
      COMMON DNORX(2500),PNORY(2500),PNORX(2500),PNORY(2500)
      COMMON DR,DZ
      COMMON NDEV1,NDEV2
      COMMON/FLAG1/FLAG1
      COMMON/MOTN/MOTN
      COMMON/FLGS/TTY,NDMP,NEDT,NSTP,NPIM
      COMMON/STUFF/ERRORS,NAME,DIVS,VCHM,UCHM
      COMMON/MOUSE/INX,INY,INSW,SWSTAT
      COMMON/LOOK/PMX,UMX,VMX,PMX1,UMX1,VMX1
      COMMON/NX/DTMAX
      LOGICAL TTY,NDMP,NEDT,NSTP,NPIM
      LOGICAL NFIB
      REAL MU
      INTEGER AND,OR,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     *  FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,AKB
      DATA INTRF,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     *  FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,AKB/1,2,4,8,16,32,
     *  64,128,256,512,1024,2048,4096,8192,16384,32768/
      DATA MASK1,MASK2,MASK3,MASK4,MASK5,MASK6,
     *  MASK7,MASK8/07777777777757,07777777773777,
     *  07777776777777,07777777777773,07777777777767,
     *  07777777737777,07777777757777,07777777767777/
      CALL PSEUD
      TYPE 301
301   FORMAT(1H ,'PROCESS OR EXAMINE?',$)
      ACCEPT 302,IDO
302   FORMAT(A1)
      IF(IDO.EQ.'E')CALL EXAMIN
      TYPE 1
1     FORMAT(1H ,'ADMAC')
      TYPE 2
2     FORMAT(1H ,'SAVED CORE?',$)
      ACCEPT 3,NYS
3     FORMAT(A1)
      IF(NYS.EQ.'Y') GO TO 32
      FLAG1=0
      TYPE 4
4     FORMAT(1H ,'INPUT FILE=',$)
      ACCEPT 5,NAME
5     FORMAT(A5)
```

```
          NAME=NAME+32
          NAME1=NAME+2
          CALL IFILE(22,NAME1)
          READ(22)NGEN
          READ(22)NCYCLE,NSTOP,NEDTM,NEDIT,OPE
          READ(22)TIME,EDTIM,EDDT,NPIT
          READ(22)BETA,EPS2,DT,VMAX,UMAX,RELAX,CUT
          READ(22)SMIN,EPS1,NBMAX,UBTO,VBTO,UBND,VBND
          READ(22)UM,MU,RHOA,GR,GZ,G,ISEC
          READ(22)VIN,UIN,DKP,DLP,NBP,DDR,DDZ
          READ(22)NEXP,NEXPP,NPART,NDIV
          READ(22)NGRID,KMAX,LMAX,KMAXZ,LMAXZ,KMAXZZ,LMAXZZ
          READ(22)KDMN,LDMN,KDMX,LDMX,MESS
          READ(22)ICRT,XMAX,YMAX,CRTRA,CRTRB,CRTZA,CRTZB
          READ(22)ITEST,IOZ,IZ,GAMA,PGAS,PGASZ,PAMB,GASV,GASVZ
          READ(22)NP,NG,NIT,H,XG,HH,HV,GG,FUDGE,NTAL,CRAX,DELZ
          READ(22)R,Z,RB,ZB
          READ(22)DRB,DZB
          READ(22)M
          READ(22)F,U,ETA,V,PSI
          READ(22)DNORX,DNORY,PNORX,PNORY
          READ(22)DR,DZ
          DTMAX=DR**2*DZ**2/(DR**2+DZ**2)
          DTMAX=.4*DTMAX/(MU+.000001)*RHOA
          DT=.5*(DT+DTMAX)-.5*ABS(DT-DTMAX)
          DTMAX=DT
          RELAX=.2*RHOA*DR**2/DT
          TYPE 6
6         FORMAT(1H ,'UPDATE?',$)
          ACCEPT 5,NYS
          IF(NYS.EQ.'N')GO TO 32
          NAME2=NAME+6
          CALL IFILE(23,NAME2)
          READ(23)M
          READ(23)U,V,P
          READ(23)DT,RHOA,TIME,NCYCLE,MU,EPS1
          READ(23)KDMN,KDMX,LDMN,LDMX,DR,DZ,KMAX,LMAX,DTMAX
          TYPE 7
7         FORMAT(1H ,'NPIT=',$)
          ACCEPT 8,NPIT
8         FORMAT(I)
          TYPE 9
9         FORMAT(1H ,'NDMPT=',$)
          ACCEPT 8,NDMPT
          TYPE 10
10        FORMAT(1H ,'NEDIT=',$)
          ACCEPT 8,NEDIT
          NEDTM=NCYCLE+NEDIT
32        CONTINUE
          TYPE 800
          IF IB=.FALSE.
800       FORMAT(1H ,'FIB RUN?',$)
          ACCEPT 801,NYS
801       FORMAT(A1)
          IF(NYS.EQ.'N')GO TO 802
          IFIB=.TRUE.
802       CONTINUE
```

```
            TYPE 11
11          FORMAT(1H ,'CREATE SHARE FILE?',$)
            ACCEPT 3,NYS
            IF (NYS.EQ.'Y')CALL FILE
            TTT=.TRUE.
            NP1M=.FALSE.
            NUMP=.FALSE.
            NEDT=.FALSE.
            NSTP=.FALSE.
            TFV=.25
            TRO=2.0
            NSOR=2
            FV=.5
33          CONTINUE
            UM=MU*DT
            DO 34 L=1,NGRID
            PSI(N)=0.0
            ETA(N)=0.0
34          CONTINUE
            DO 46 L=2,LMAX2
            KMM=(L-1)*KMAX
            IF (NGEN .EQ. 0) GO TO 36
35          UP=TFV*(U(KMM+1)+U(KMM+2))**NSOR*RHOA*R(2)
            GO TO 39
36          UBAR=FV*(U(KMM+1)+U(KMM+2))*RHOA*R(2)
            IF(UBAR)38,37,37
37          UR=UBAR*U(KMM+1)
            GO TO 39
38          UR=UBAR*U(KMM+2)
39          DO 46 K=2,KMAX22
            KM=K+KMM
            UL=UR
            IF(NGEN .EQ. 0) GO TO 41
40          UP=TFV*(U(KM)+U(KM+1))**NSOR*RHOA*R(K+1)
            GO TO 44
41          UBAR=FV*(U(KM)+U(KM+1))*RHOA*R(K+1)
            IF(UBAR)42,43,43
42          UR=UBAR*U(KM+1)
            GO TO 44
43          UR=UBAR*U(KM)
44          IF(((M(KM).AND.EMP).NE.EMP).AND.((M(KM+1).AND.EMP)
     *      .NE.EMP)) GO TO 45
            GO TO 46
45          ETA(KM)=ETA(KM)+RHOA*U(KM)
            ETA(KM)=ETA(KM)-DT*((UR-UL)/(DRB(K)*RB(K)))
46          CONTINUE
            DO 61 K=2,KMAX22
            VT=0.0
            DO 61 L=2,LMAX2
            KT=K+L*KMAX
            KM=KT-KMAX
            KB=KM-KMAX
            VB=VT
            VBAR=FV*(V(KM)+V(KM+1))
            IF((((M(KM).AND.EMP).EQ.EMP).AND.((M(KM+1).AND.EMP)
     *      .EQ.EMP)) GO TO 47
            GO TO 50
```

```
47        IF(((M(KT).AND.EMP).NE.EMP).AND.((M(KT+1).AND.EMP)
     *    .NE.EMP)) GO TO 49
          VT=0.0
          GO TO 61
49        VT=RHOA*U(KT)+VBAR
          GO TO 61
50        IF(((M(KM).AND.EMP).NE.EMP).AND.((M(KM+1).AND.EMP)
     *    .NE.EMP)) GO TO 55
          IF(((M(KT).AND.EMP).NE.EMP).AND.((M(KT+1).AND.EMP)
     *    .NE.EMP)) GO TO 52
          GO TO 61
52        IF(VBAR)53,54,54
53        VT=RHOA*U(KT)*VBAR
          GO TO 61
54        VT=RHOA*VBAR*U(KM)
          GO TO 61
55        IF(VBAR)56,58,58
56        IF(((M(KT).AND.EMP).EQ.EMP).AND.((M(KT+1).AND.EMP)
     *    .EQ.EMP)) GO TO 58
          VT=RHOA*VBAR*U(KT)
          GO TO 59
58        VT=RHOA*VBAR*U(KM)
59        IF(((M(KB).AND.OUT).EQ.OUT).OR.((M(KT).AND.OUT)
     *    .EQ.OUT)) GO TO 61
60        ETA(KM)=ETA(KM)-DT*((VT-VB)/DZ)
61        CONTINUE
          DO 73 K=2,KMAX2
          IF(NGEN.EQ.0) GO TO 63
62        VT=TFV*(V(K)+V(K+KMAX))**NSQR*RHOA
          GO TO 66
63        VBAR=FV*(V(K)+V(K+KMAX))*RHOA
          IF(VBAR)64,65,65
64        VT=VBAR*V(K+KMAX)
          GO TO 66
65        VT=VBAR*V(K)
66        DO 73 L=2,LMAX22
          KT=KTL*KMAX
          KM=KT-KMAX
          VB=VT
          IF(NGEN.EQ.0) GO TO 68
67        VT=TFV*(V(KM)+V(KT))**NSQR*RHOA
          GO TO 71
68        VBAR=FV*(V(KM)+V(KT))*RHOA
          IF(VBAR)69,70,70
69        VT=VBAR*V(KT)
          GO TO 71
70        VT=VBAR*V(KM)
71        IF(((M(KM).AND.EMP).NE.EMP).AND.((M(KT).AND.EMP)
     *    .NE.EMP)) GO TO 72
          GO TO 73
72        PSI(KM)=PSI(KM)+RHOA*V(KM)
          PSI(KM)=PSI(KM)-DT*((VT-VB)/DZB(L))
73        CONTINUE
          DO 88 L=2,LMAX22
          KAM=L*KMAX
          UB=0.0
          DO 88 K=2,KMAX2
```

```
              KT=K+KMM
              KM=KT-KMAX
              UL=UR
              UBAR=FV*(U(KM)+U(KT))*RB(K)
              IF(((M(KM).AND.EMP).EQ.EMP).AND.((M(KT).AND.EMP)
     *        .EQ.EMP)) GO TO 74
              GO TO 77
74            IF((((M(KM+1).AND.EMP).NE.EMP).AND.((M(KT+1).AND.EMP)
     *        .NE.EMP)) GO TO 76
              UL=0.0
              GO TO 88
76            UR=RHOA*UBAR*V(KM+1)
              GO TO 88
77            IF((((M(KM).AND.EMP).NE.EMP).AND.((M(KT).AND.EMP)
     *        .NE.EMP)) GO TO 82
              IF((((M(KM+1).AND.EMP).NE.EMP).AND.((M(KT+1).AND.EMP)
     *        .NE.EMP)) GO TO 79
              GO TO 88
79            IF(UBAR) 80,81,81
80            UR=RHOA*UBAR*V(KM+1)
              GO TO 88
81            UR=RHOA*UBAR*V(KM)
              GO TO 88
82            IF(UBAR) 83,85,85
83            IF((((M(KM+1).AND.EMP).EQ.EMP).AND.((M(KT+1).AND.EMP)
     *        .EQ.EMP)) GO TO 85
84            UR=RHOA*UBAR*V(KM+1)
              GO TO 86
85            UR=RHOA*UBAR*V(KM)
86            IF((((M(KM+1).AND.OUT).EQ.OUT).OR.((M(KM-1).AND.OUT)
     *        .EQ.OUT)) GO TO 88
              PSI(KM)=PSI(KM)-DT*((UR-UL)/(DR*R(K)))
88            CONTINUE
              IF(MU) 106,106,89
89            DO 97 L=2,LMAX2
              KTT=L*KMAX
              DO 97 K=2,KMAX22
              KT=K+KTT
              KM=KT-KMAX
              KB=KM-KMAX
              IF((((M(KM).AND.EMP).NE.EMP).AND.((M(KM+1).AND.EMP)
     *        .NE.EMP))GO TO 90
              GO TO 97
90            IF((((M(KB).AND.EMP).EQ.EMP).AND.((M(KB+1).AND.EMP)
     *        .EQ.EMP)) GO TO 91
              GO TO 92
91            UBOT=U(KM)
              GO TO 93
92            UBOT=U(KB)
93            IF((((M(KT).AND.EMP).EQ.EMP).AND.((M(KT+1).AND.EMP)
     *        .EQ.EMP)) GO TO 94
              GO TO 95
94            UTOP=U(KM)
              GO TO 96
95            UTOP=U(KT)
96            ETA(KM)=ETA(KM)+UM*((UTOP+UBOT-TWO*U(KM))/
     *        DZ**NSQR)
```

```
                ETA(KM)=ETA(KM)-UM*((V(KM+1)-V(KB+1)-V(KM)+V(KB)))/ 168
        *       (DRB(K)*DZ))
97              CONTINUE
                DO 105 K=2,KMAX2
                DO 105 L=2,LMAX22
                KT=K+L*KMAX
                KM=KT-KMAX
                IF((((M(KM).AND.EMP).NE.EMP).AND.((M(KT).AND.EMP)
        *       .AND.EMP)) GO TO 98
                GO TO 105
98              IF((((M(KM-1).AND.EMP).EQ.EMP).AND.((M(KT-1).AND.EMP)
        *       .EQ.EMP)) GO TO 99
                GO TO 100
99              VLEFT=V(KM)
                GO TO 101
100             VLEFT=V(KM-1)
101             IF((((M(KM+1).AND.EMP).EQ.EMP).AND.((M(KT+1).AND.EMP)
        *       .EN.EMP)) GO TO 102
                GO TO 103
102             VRGHT=V(KM)
                GO TO 104
103             VRGHT=V(KM+1)
104             TEMPR=(U(KT)-U(KM))/DZB(L)-(VRGHT-V(KM))/DRB(K)
                TEMPL=(U(KT-1)-U(KM-1))/DZB(L)-(V(KM)-VLEFT)/DRB(K-1)
                PSI(KM)=PSI(KM)-UM*((TEMPR*RB(K)-TEMPL*RB(K-1))
        *       /(DR*R(K)))
105             CONTINUE
106             CONTINUE
107             CONTINUE
                DO 204 K=2,KMAX2
                PSI(K)=PSI(K+4*KMAX)-2.*PSI(K+3*KMAX)+2.*PSI(K+KMAX)
204             CONTINUE
                LPS=LPS2
                CALL PPES(LPS)
                DO 120 I=1,NGRID
                PMX1=AMAX1(ABS(P(I)),PMX1)
                UMX1=AMAX1(ABS(U(I)),UMX1)
120             VMX1=AMAX1(ABS(V(I)),VMX1)
                NCYCLE=NCYCLE+1
                TIME=TIME+DT
                IF(VMAX) 110,110,109
109             DT=EPS1/VMAX
110             CONTINUE
                IF(DT-DTMAX)112,112,111
111             DT=DTMAX
112             CONTINUE
                RELAX=BETA*RHOA*DR**2/DT
                IF(NFIN)GO TO 305
                IF(NSTP)GO TO 119
                IF(.NOT.NDMP)GO TO 115
                CALL ABSAV
                GO TO 117
115             IF(NCYCLE-NDMPT)118,116,116
116             CALL ABSAV
117             NDMP=.FALSE.
                NDMPT=NDMPT+NDUMP
118             IF(.NOT.NEDT)GO TO 123
```

```
         CALL EDIT
         NEDT=.FALSE.
         GO TO 33
123      IF(NCYCLE-NEDTM)33,121,121
121      NEDTM=NEDTM+NEDIT
         CALL EDIT
         GO TO 33
119      CALL EDIT
         CALL ABSAV
         CALL EXIT
805      IF(NCYCLE-NEDTM)807,806,806
806      NEDTM=NEDTM+NEDIT
         TYPE 823,NCYCLE
823      FORMAT(1H ,'EDIT AT CYCLE ',I3)
         CALL EDIT
807      CALL ABSAV
         CALL EXIT
         RETURN
         END
```

```
      SUBROUTINE PRES(EPS)
      COMMON NVAC,NGEN,UAC,VAC,TM1,TM2,TM3
      COMMON NCYCLE,NSTOP,NEDTM,NEDIT,OPE
      COMMON TIME,EDTIM,EDDT,NPIT,NITER
      COMMON BETA,EPS2,DT,VMAX,UMAX,RELAX,CUT
      COMMON SMIN,EPS1,NBMAX,UBTO,VBTO,UBND,VBND
      COMMON UM,MU,RHOA,GR,GZ,G,ISEC
      COMMON VIN,UIN,DKP,DLP,NBP,DDR,DDZ
      COMMON NEXP,NEXPP,NPART,NDIV
      COMMON NGRID,KMAX,LMAX,KMAXZ,LMAXZ,KMAXZZ,LMAXZZ
      COMMON KDMN,LDMN,KDMX,LDMX,MESS(7)
      COMMON ICRT,XMAX,YMAX,CRTRA,CRTRB,CRTZA,CRTZB
      COMMON ITEST,IO2,I2,GAMA,PGAS,PGASZ,PAMB,GASV,GASVZ
      COMMON NF,NG,NII,H,XG,HH,HV,GG,FUDGE,NTAL,CRAX,DELZ
      COMMON R(150),Z(150),RD(150),ZB(150)
      COMMON DRB(150),DZB(150)
      COMMON M(2500)
      COMMON P(2500),U(2500),ETA(2500),V(2500),PSI(2500)
      COMMON DNORX(2500),DNORY(2500),PNORX(2500),PNORY(2500)
      COMMON DR,DZ
      COMMON NDEV1,NDEV2
      COMMON/FLAG1/FLAG1
      COMMON/FLGS/TTY,NDMP,NEDT,NSTP,NPIM
      COMMON/STUFF/ERRORS,NAME,DIVS,VCHM,UCHM
      LOGICAL TTY,NDMP,NEDT,NSTP,NPIM
      REAL MU
      INTEGER AND,OR,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     *  FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,ARB
      DATA INTRB,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     *  FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,ARB/1,2,4,8,16,32,
     *  64,128,256,512,1024,2048,4096,8192,16384,32768/
      DATA MASK1,MASK2,MASK3,MASK4,MASK5,MASK6,
     *  MASK7,MASK8/0777777777757,0777777773777,
     *  0777777677777,0777777777773,0777777777767,
     *  0777777737777,0777777757777,0777777767777/
      PI=3.1415926
      MAST=43012
      NPLS=43016
      LOGICAL TEST
      LOGICAL TA,TB,TC,IV,TH
      NEX=0
      NIL=0
      CALL VEL(2,NIL,NIL,NIL,1)
 1    MM=0
 2    NITER=0
 3    NITER=NITER+1
      LNORM=0.
      PNORM=0.
      DIVSI=0
      TEMPSI=0
      DO 44 L=2,LMAXZ
      NIT=L*KMAX
      DO 44 K=2,KMAXZ
      KP=K
      LP=L
      NT=KT I+KP
      NW=NIT-KMAX
```

```fortran
      NB=NM-KMAX
      IF(((M(NM).AND.FULL).EQ.FULL).AND.((M(NM).AND.OB).NE.OB))
     *  GO TO 4
      IF(M(NM).EQ.43012)GO TO 4
      IF(M(NM).EQ.43016)GO TO 4
      GO TO 5
4     DIV=(U(NM)*RB(K)-U(NM-1)*RB(K-1))/
     *  (R(K)*DR)
      DIV=DIV+(V(NM)-V(NB))/DZ
      GO TO 39
5     CONTINUE
      IF((M(NM).AND.OK).EQ.OK) GO TO 6
      GO TO 43
6     DELR=DR
      DELZ=DZ
      IF(PNORY(NM)-Z(LP)) 7,7,8
7     LB=LP-1
      GO TO 9
8     CONTINUE
      LB=LP
9     KT=LB*KMAX+KP
      KM=(LB-1)*KMAX+KP
      SX=(R(KP)-PNORX(NM))/DELR
      SY=(ZB(LB)-PNORY(NM))/DELZ
      IF(U(KT-1))11,13,11
10    U1=U(NM-1)
      GO TO 12
11    U1=U(KT-1)
12    IF(U(KT) )14,13,14
13    U2=U(NM)
      GO TO 15
14    U2=U(KT)
15    IF(U(KM-1))17,16,17
16    U3=U(NM-1)
      GO TO 18
17    U3=U(KM-1)
18    IF(U(KM)) 20,19,20
19    U4=U(NM)
      GO TO 21
20    U4=U(KM)
21    UP=(.5+SX)*(.5-SY)*U1+(.5-SX)*(.5-SY)*U2
      UP=UP+(.5+SX)*(.5+SY)*U3+(.5-SX)*(.5+SY)*U4
      IF(PNORX(NM)-R(KP)) 22,22,23
22    KB=KP-1
      GO TO 24
23    KB=KP
24    KU=(LP-2)*KMAX+KB
      KM=(LP-1)*KMAX+KB
      SX=(RB(KB)-PNORX(NM))/DELR
      SY=(Z(LP)-PNORY(NM))/DELZ
      IF(V(KM)) 26,25,26
25    V1=V(NM)
      GO TO 27
26    V1=V(KM)
27    IF(V(KM+1)) 29,28,29
28    V2=V(NM)
      GO TO 30
```

```
29          V2=V(NM+L)
30          IF(V(KD)) 32,31,32
31          V3=V(NB)
            GO TO 33
32          V3=V(KD)
33          IF(V(KD+1)) 35,34,35
34          V4=V(NB)
            GO TO 36
35          V4=V(KD+1)
36          VP=(.5+SX)*(.5-SY)*V1+(.5-SX)*(.5-SY)*V2
            VP=VP+(.5+SX)*(.5+SY)*V3+(.5-SX)*(.5+SY)*V4
            DOT=DNORX(NM)*UP+DNORY(NM)*VP
38          DIV=DOT/DR
39          IF(ABS(DIV).LT.10E-20)DIV=0.0
            TEMP=RELAX*DIV
            IF(DIVS1.GT.ABS(DIV))GO TO 7022
            DIVS1=ABS(DIV)
            KMLOC=K
            LMLOC=L
7022        P(NM)=P(NM)-TEMP
40          IF((M(NT).AND.OUT).EQ.OUT) GO TO 41
            GO TO 42
41          P(NM)=0.
            TEMP=0.
42          ENORM=ENORM+TEMP*TEMP
            PNORM=PNORM+P(NM)*P(NM)
43          CALL VEL(1,NM,K,L,0)
44          CONTINUE
            DO 45 L=2,LMAX2
            KL=2+(L-1)*KMAX
            P(KL-1)=P(KL)-GR*RHOA*(R(2)-R(1))
45          CONTINUE
            DO 46 L=2,LMAX22
            KR=L*KMAX
            P(KR)=P(KR-1)+GR*RHOA*(R(KMAX)-R(KMAX2))
46          CONTINUE
            DO 47 K=2,KMAXZ
            KT=K+(LMAX2-1)*KMAX
            KTT=K+LMAX2*KMAX
            KB=K+KMAX
            KBB=K
            P(KTT)=P(KT)
            IF((M(K).AND.OUT).EQ.OUT)GO TO 47
            P(KBB)=P(KB)
47          CONTINUE
            CALL VEL(1,NIL,NIL,NIL,1)
            ERROR=SQRT(ENORM/(PNORM+.0000001))
            ERRORS=ERROR
            DIVS=DIVS1
            TYPE 57,NCYCLE
            TYPE 58,DIVS
            TYPE 7023,KMLOC,LMLOC
7023        FORMAT(1H ,'AT K=',I3,',L=',I3)
            TYPE 48,ERROR
57          FORMAT(1H ,'CYCLE ',I3)
58          FORMAT(1H ,'MAX DIVERGENCE=',F)
48          FORMAT(1H ,'ERROR=',F)
```

```
            IF(ERROR-EPS)49,55,55
55          IF(.NOT.NPIM)GO TO 50
            NPIM=.FALSE.
            RETURN
50          IF(INITER-NPIT)3,51,51
51          WRITE(1,57)NCYCLE
            WRITE(1,56)DIVS
            WRITE(1,48)ERROR
            END FILE 1
            CALL APFLE
49          CONTINUE
            RETURN
            END
```

```
      SUBROUTINE VEL(NA1,NA2,NA3,NA4,NA5)
      COMMON NVAC,NGEN,UAC,VAC,TM1,TM2,TM3
      COMMON NCYCLE,NSTOP,NEDTM,NEDIT,OPE
      COMMON TIME,EDTIM,EPDT,NPIT,NITER
      COMMON BETA,EPS2,DT,VMAX,UMAX,RELAX,CUT
      COMMON SMIN,EPS1,NBMAX,UBTO,VBTO,UBND,VBND
      COMMON UM,MU,RHOA,GR,GZ,G,ISEC
      COMMON VIN,UIN,DRP,DLP,NBP,DDR,DDZ
      COMMON NEXP,NEXPP,NPART,NDIV
      COMMON NGRID,KMAX,LMAX,KMAXZ,LMAXZ,KMAXZZ,LMAXZZ
      COMMON KDMN,LDMN,KDMX,LDMX,MFSS(7)
      COMMON ICRT,XMAX,YMAX,CRTRA,CRTRB,CRTZA,CRTZB
      COMMON ITEST,IOZ,IZ,GAMA,PGAS,PGASZ,PAMB,GASV,GASVZ
      COMMON NF,NG,NIT,H,XG,HH,HV,GG,FUDGE,NTAL,CRAX,DELZ
      COMMON R(150),Z(150),RB(150),ZB(150)
      COMMON DRB(150),DZB(150)
      COMMON M(2500)
      COMMON P(2500),U(2500),ETA(2500),V(2500),PSI(2500)
      COMMON DNORX(2500),DNORY(2500),PNORX(2500),PNORY(2500)
      COMMON DR,DZ
      COMMON NDEV1,NDEV2
      COMMON/FLAG1/FLAG1
      COMMON/FLGS/ITY,NDMP,NEDT,NSTP,NPIM
      COMMON/STUFF/ERRORS,NAME,DIVS,VCHM,UCHM
      LOGICAL ITY,NDMP,NEDT,NSTP,NPIM
      REAL MU
      INTEGER AND,OR,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     * FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,AKB
      DATA INTRF,CNTRB,SUP,FULL,EMP,BND,IN,OUT,
     * FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,AKB/1,2,4,8,16,32,
     * 64,128,256,512,1024,2048,4096,8192,16384,32768/
      DATA MASK1,MASK2,MASK3,MASK4,MASK5,MASK6,
     * MASK7,MASK8/0777777777757,0777777773777,
     * 0777777677777,0777777777773,0777777777767,
     * 0777777737777,0777777757777,0777777767777/
      PI=3.1415926
      KSIG=NA1
      KM=NA2
      K=NA3
      L=NA4
      KP=NA5

C
      FV=.5
C     THIS ROUTINE COMPUTES ALL OF THE CELL VELOCITIES.
C     THE PRESSURE GRADIENTS ARE CALCULATED FOR BOUNDARY
C     PRESSURES LOCATED AT THE MID POINTS OF THE LAGRANGE
C     BOUNDARY SEGMENTS. APPROXIMATE LINEAR INTERPOLATION
C     IS USED.
C
      LOGICAL TEST
      VMAX=0.0
      LMZ=LMAXZ
      KMZ=KMAXZ
      IF(KP.EQ.0)GO TO 73
      UCHM=0.
      VCHM=0.
      DO 39 L=2,LMZ
```

```
            KTT=L*KMAX
            DO 39 K=2,KMZ
            KT=K+KTT
            KM=KT-KMAX
            KB=KM-KMAX
            KTZ=KT+KMAX
            GO TO 74
73          KT=KM+KMAX
            KB=KM-KMAX
            KTZ=KT+KMAX
            KMZ=K
            LMZ=L
74          IF(((M(KM).AND.FULL).EQ.FULL).OR.(((M(KM).AND.SUR)
     *      .EQ.SUR).AND.((M(KM).AND.COR).NE.COR))) GO TO 1
            GO TO 39
C
C           U COMPONENT OF VELOCITY
C
1           IF((M(KM+1).AND.BND).EQ.BND) GO TO 20
2           IF(((M(KM+1).AND.EMP).EQ.EMP).OR.((M(KM+1).AND.COR)
     *      .EQ.COR)) GO TO 3
            GO TO 5
3           GO TO (20,4),NSIG
4           U(KM)=U(KM)-GR*DT
            GO TO 20
5           XC=R(K)
            IF(((M(KM).AND.OK).EQ.OK).AND.((M(KM-1).AND.COR)
     *      .EQ.COR)) GO TO 6
            GO TO 7
6           XC=PNORX(KM)
7           XA=R(K+1)
            IF(((M(KM+1).AND.OK).EQ.OK).AND.((M(KM+2).AND.COR)
     *      .EQ.COR)) GO TO 8
            GO TO 9
8           XA=PNORX(KM+1)
9           PA=P(KM)
            IF(((M(KM).AND.OK).EQ.OK).AND.((M(KT).AND.COR)
     *      .EQ.COR)) GO TO 10
            GO TO 11
10          P2=P(KM)
            P1=P(KB)
            Y2=PNORY(KM)
            Y1=Z(L-1)
            GO TO 13
11          IF(((M(KM).AND.OK).EQ.OK).AND.((M(KB).AND.COR)
     *      .EQ.COR)) GO TO 12
            GO TO 14
12          P2=P(KT)
            P1=P(KM)
            Y2=Z(L+1)
            Y1=PNORY(KM)
13          SLP=(P2-P1)/(Y2-Y1)
            ORD=P1-SLP*Y1
            XC=R(K)
            PA=SLP*Z(L)+ORD
14          PB=P(KM+1)
            IF(((M(KM+1).AND.OK).EQ.OK).AND.((M(KT+1).AND.COR)
```

```
      *     .EQ.COR)) GO TO 15
            GO TO 16
15          P2=P(KM+1)
            P1=P(KB+1)
            Y2=PNORY(KM+1)
            Y1=Z(L-1)
            GO TO 18
16          IF(((M(KM+1).AND.OK).EQ.OK).AND.((M(KB+1).AND.COR)
      *     .EQ.COR)) GO TO 17
            GO TO 19
17          P2=P(KT+1)
            P1=P(KM+1)
            Y2=Z(L+1)
            Y1=PNORY(KM+1)
18          SLP=(P2-P1)/(Y2-Y1)
            ORD=P1-SLP*Y1
            XA=R(K+1)
            PB=SLP*Z(L)+ORD
19          UOLD=U(KM)
            U(KM)=ETA(KM)+DT*((PA-PB)/(XA-XC))
            U(KM)=U(KM)/RHOA-GR*DT
            UCH=ABS(UOLD-U(KM))
            UCHM=AMAX1(UCH,UCHM)
C
C
C     V COMPONENT OF VELOCITY
C
20          IF((M(KT).AND.BND).EQ.BND) GO TO 39
21          IF(((M(KT).AND.EMP).EQ.EMP).OR.((M(KT).AND.COR)
      *     .EQ.COR)) GO TO 22
            GO TO 24
22          GO TO (39,23),NSIG
23          V(KM)=V(KM)-G2*DT
            GO TO 39
24          YC=Z(L)
            IF(((M(KM).AND.OK).EQ.OK).AND.((M(KB).AND.COR)
      *     .EQ.COR)) GO TO 25
            GO TO 26
25          YC=PNORY(KM)
26          YA=Z(L+1)
            IF(((M(KT).AND.OK).EQ.OK).AND.((M(KTZ).AND.COR)
      *     .EQ.COR)) GO TO 27
            GO TO 28
27          YA=PNORY(KT)
28          PA=P(KM)
            IF(((M(KM).AND.OK).EQ.OK).AND.((M(KM+1).AND.COR)
      *     .EQ.COR)) GO TO 29
            GO TO 30
29          P2=P(KM)
            P1=P(KM-1)
            X2=PNORX(KM)
            X1=R(K-1)
            GO TO 32
30          IF(((M(KM).AND.OK).EQ.OK).AND.((M(KM-1).AND.COR)
      *     .EQ.COR)) GO TO 31
            GO TO 33
31          P2=P(KM+1)
            P1=P(KM)
```

```
          X1=PNORX(KM)
          X2=R(K+1)
32        SLP=(P2-P1)/(X2-X1)
          ORD=P1-SLP*X1
          YC=Z(L)
          PA=SLP*R(K)+ORD
33        PB=P(KT)
          IF(((M(KT).AND.OK).EQ.OK).AND.((M(KT+1).AND.COR)
     *    .EQ.COR)) GO TO 34
          GO TO 35
34        P2=P(KT)
          P1=P(KT-1)
          X2=PNORX(KT)
          X1=R(K-1)
          GO TO 37
35        IF(((M(KT).AND.OK).EQ.OK).AND.((M(KT-1).AND.COR)
     *    .EQ.COR)) GO TO 36
          GO TO 38
36        P2=P(KT+1)
          P1=P(KT)
          X2=R(K+1)
          X1=PNORX(KT)
37        SLP=(P2-P1)/(X2-X1)
          ORD=P1-SLP*X1
          YA=Z(L+1)
          PB=SLP*R(K)+ORD
38        VOLD=V(KM)
          V(KM)=PSI(KM)+DT*((PA-PB)/(YA-YC))
          V(KM)=V(KM)/RHOA-GZ*DT
          VCH=ABS(VOLD-V(KM))
          VCHM=AMAX1(VCH,VCHM)
          UMAX=ABS(U(KM))+ABS(V(KM))
          VMAX=FV*(ABS(VMAX-UMAX)+VMAX+UMAX)
39        CONTINUE
C
C
C         USE NOSLIP BOUNDARY CONDITIONS ON OB CELLS...
C
          IF(KP.EQ.0)GO TO 75
          CALL NOSLIP(NIL,NIL,NIL)
          GO TO 76
75        CALL NOSLIP(KM,K,L)
76        CONTINUE
C
C
C         BOUNDARY CONDITIONS ON VELOCITIES AT EDGE OF MESH.
C
          DO 50 K=2,KMAX2
          KT=K+(LMAX2-1)*KMAX
          KTB=KT-KMAX
          KTT=KT+KMAX
          KB=K
          KBT=KB+KMAX
          IF((M(KT).AND.IN).EQ.IN) GO TO 49
          GO TO 50
49        V(KT)=VIN
          V(KTT)=V(KT)
          U(KTT)=0.
          GO TO 54
```

```
50      IF((M(KTT).AND.OUT).EQ.OUT) GO TO 51
        GO TO 52
51      V(KT)=V(KTB)
        U(KTT)=U(KT)
        V(KTT)=V(KTB)
        GO TO 54
52      IF((M(KTT).AND.BND).EQ.BND) GO TO 53
        GO TO 54
53      V(KT)=0.
        U(KTT)=U(KT)
        V(KTT)=-V(KTB)
54      IF((M(KB).AND.IN).EQ.IN) GO TO 55
        GO TO 56
55      V(KB)=VIN
        U(KB)=0.
        GO TO 60
56      IF((M(KB).AND.OUT).EQ.OUT) GO TO 57
        GO TO 58
57      V(K)=(PSI(K)-DT*P(KBT)/DZB(1))/RHOA
        U(K)=U(KBT)
        GO TO 60
58      IF((M(KB).AND.BND).EQ.BND) GO TO 59
        GO TO 60
59      V(KB)=0.
        U(KB)=U(KBT)
60      CONTINUE
        DO 72 L=1,LMAX
        KK=(L-1)*KMAX
        LR=KK+KMAX
        LL=2*KK
        IF((M(LL-1).AND.IN).EQ.IN) GO TO 61
        GO TO 62
61      U(LL-1)=UIN
        V(LL-1)=0.
        GO TO 66
62      IF((M(LL-1).AND.OUT).EQ.OUT) GO TO 63
        GO TO 64
63      U(LL-1)=U(LL)
        V(LL-1)=V(LL)
        GO TO 66
64      IF((M(LL-1).AND.BND).EQ.BND) GO TO 65
        GO TO 66
65      U(LL-1)=0.
        V(LL-1)=V(LL)
        GO TO 72
66      IF((M(LR+1).AND.IN).EQ.IN) GO TO 67
        GO TO 68
67      U(LR)=UIN
        U(LR+1)=U(LR)
        V(LR+1)=V(LR)
        GO TO 72
68      IF((M(LR+1).AND.OUT).EQ.OUT) GO TO 69
        GO TO 70
69      U(LR)=U(LR-1)
        U(LR+1)=U(LR)
        V(LR+1)=V(LR)
        GO TO 72
```

```
70       IF((M(LR+1).AND.BND).EQ.BND) GO TO 71
         GO TO 72
71.      U(LR)=0.
         U(LR+1)=-U(LR-1)
         V(LR+1)=V(LR)
72       CONTINUE
         RETURN
         END
```

```
      SUBROUTINE VEL55(NA6,NA7,NA8)
      COMMON NVAC,NGEH,UAC,VAC,TM1,TM2,TM3
      COMMON NCYCLE,NSTOP,NEDTM,NEDIT,OPE
      COMMON TIME,EDTIM,EDDT,NPIT,NITER
      COMMON BETA,EPS2,DT,VMAX,UMAX,RELAX,CUT
      COMMON SMIN,EPS1,NBMAX,UBTO,VBTO,UBND,VBND
      COMMON UM,MU,RHOA,GR,GZ,G,ISEC
      COMMON VIN,UIN,DKP,DLP,NBP,DDK,DDZ
      COMMON NEXP,NEXPP,NPART,NDIV
      COMMON NGRID,KMAX,LMAX,KMAXZ,LMAXZ,KMAXZZ,LMAXZZ
      COMMON KDMN,LDMIN,KDMX,LDMX,MESS(7)
      COMMON ICUT,XMAX,YMAX,CRTRA,CRTRB,CRTZA,CRTZB
      COMMON ITEST,IO2,I2,GAMA,PGAS,PGASZ,PAMB,GASV,GASVZ
      COMMON NF,NG,N11,N,XG,NH,NV,GG,FUDGE,NTAL,CRAX,DELZ
      COMMON R(150),Z(150),RB(150),ZB(150)
      COMMON DRB(150),DZB(150)
      COMMON M(2500)
      COMMON P(2500),U(2500),ETA(2500),V(2500),PSI(2500)
      COMMON UNORX(2500),DNORY(2500),PNORX(2500),PNORY(2500)
      COMMON DR,DZ
      COMMON NDEV1,NDEV2
      COMMON/FLAG1/FLAG1
      COMMON/FLGS/TTY,NDMP,NEDT,NSTP,HPIM
      LOGICAL TTY,NEDT,NDMP,NSTP,HPIM
      REAL MU
      INTEGER AND,OR,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     *  FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,ARB
      DATA INTRF,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     *  FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,ARB/1,2,4,8,16,32,
     *  64,128,256,512,1024,2048,4096,8192,16384,32768/
      DATA MASK1,MASK2,MASK3,MASK4,MASK5,MASK6,
     *  MASK7,MASK8/0777777777757,0777777773777,
     *  0777777677777,0777777777773,0777777777767,
     *  0777777757777,0777777757777,0777777767777/
      PI=3.1415926
      KM=NA8
      K=NA7
      L=NA6
      LOGICAL TEST
      LMZ=LMAXZ
      KMZ=KMAXZ
      IF(KM.NE.0)GO TO 10
      DO 1 L=2,LMZ
      KMM=L*KMAX
      DO 1 K=2,KMZ
      KT=K+KMM
      KM=KT-KMAX
      KB=KM-KMAX
      GO TO 11
   10 KT=KM+KMAX
      KB=KM-KMAX
      KMZ=K
      LMZ=L
   11 CONTINUE
      IF(((M(KM).AND.SUR).EQ.SUR).OR.
     *  ((M(KM).AND.OK).EQ.OK)) GO TO 2
      GO TO 1
```

```
2        IF((.NOT.((((M(KM+1).AND.EMP).EQ.EMP).OR.
     *   ((M(KT).AND.EMP).EQ.EMP).OR.((M(KB).AND.EMP).EQ.EMP)))
     *   .AND.(((M(KM-1).AND.EMP).EQ.EMP)
     *   .OR.((M(KM-1).AND.COR).EQ.COR)).AND.((M(KM-1).AND.BND).NE.BND)
     *   .AND.(.NOT.(((M(KM+1).AND.COR).EQ.COR).OR.((M(KT).AND.
     *   COR).EQ.COR).OR.((M(KB).AND.COR).EQ.COR)))) GO TO 3
         GO TO 4
3        U(KM-1)=R(K)*DR*((V(KM)-V(KB))/(RB(K-1)*DZ))
         U(KM-1)=U(KM-1)+U(KM)*(RB(K)/RB(K-1))
         GO TO 1
4        IF((.NOT.((((M(KM-1).AND.EMP).EQ.EMP).OR.
     *   ((M(KT).AND.EMP).EQ.EMP).OR.((M(KB).AND.EMP).EQ.EMP))).AND.
     *   (((M(KM+1).AND.EMP).EQ.EMP).OR.((M(KM+1).AND.COR).EQ.COR))
     *   .AND.((M(KM+1).AND.BND).NE.BND).AND.(.NOT.(((
     *   M(KM-1).AND.COR).EQ.COR).OR.((M(KT).AND.COR).EQ.COR)
     *   .OR.((M(KB).AND.COR).EQ.COR)))) GO TO 5
         GO TO 6
5        U(KM)=U(KM-1)*(RB(K-1)/RB(K))
         U(KM)=U(KM)-R(K)*DR*((V(KM)-V(KB))/(RB(K)*DZ))
         GO TO 1
6        IF((.NOT.((((M(KM-1).AND.EMP).EQ.EMP).OR.((M(KM+1).AND.EMP)
     *   .EQ.EMP).OR.((M(KT).AND.EMP).EQ.EMP))).AND.(((M(KB).AND.
     *   EMP).EQ.EMP).OR.((M(KB).AND.COR).EQ.COR)).AND.
     *   ((M(KB).AND.BND).NE.BND).AND.(.NOT.(((M(KM-1).AND.COR)
     *   .EQ.COR).OR.((M(KM+1).AND.COR).EQ.COR).OR.
     *   ((M(KT).AND.COR).EQ.COR)))) GO TO 7
         GO TO 8
7        V(KB)=V(KM)+DZ*((RB(K)*U(KM)-RB(K-1)*U(KM-1))
     *   /(R(K)*DR))
         GO TO 1
8        IF((.NOT.((((M(KM-1).AND.EMP).EQ.EMP).OR.((M(KM+1).AND.EMP).EQ.EMP
     *   .OR.((M(KB).AND.EMP).EQ.EMP))).AND.(((M(KT).AND.EMP).EQ.EMP)
     *   .OR.((M(KT).AND.COR).EQ.COR)).AND.((M(KT).AND.BND).NE.BND)
     *   .AND.(.NOT.(((M(KM-1).AND.COR).EQ.COR).OR.((M(KM+1).AND.
     *   COR).EQ.COR).OR.((M(KB).AND.COR).EQ.COR)))) GO TO 9
         GO TO 1
9        V(KM)=V(KB)-DZ*((RB(K)*U(KM)-RB(K-1)*U(KM-1))
     *   /(R(K)*DR))
1        CONTINUE
         RETURN
         END
```

```
      SUBROUTINE NOSLIP(NA6,NA7,NA8)
      COMMON NVAC,NGEN,UAC,VAC,TM1,TM2,TM3
      COMMON NCYCLE,NSTOP,NEDTM,NEDIT,OPE
      COMMON TIME,EDTIM,EDDT,NPIT,NITER
      COMMON BETA,EPS2,DT,VMAX,UMAX,RELAX,CUT
      COMMON SMIN,EPS1,NBMAX,UBTO,VBTO,UBND,VBND
      COMMON UM,MU,RHOA,GR,GZ,G,ISEC
      COMMON VIN,UIN,DKP,DLP,NBP,DDR,DDZ
      COMMON NEXP,NEXPP,NPART,NDIV
      COMMON NGRID,KMAX,LMAX,KMAXZ,LMAXZ,KMAXZZ,LMAXZZ
      COMMON KDMN,LDMN,KDMX,LDMX,MESS(7)
      COMMON ICRT,XMAX,YMAX,CRTRA,CRTRB,CRTZA,CRTZB
      COMMON ITEST,IOZ,IZ,GAMA,PGAS,PGASZ,PAMB,GASV,GASVZ
      COMMON NF,NG,NIT,H,XG,HH,HV,GG,FUDGE,NTAL,CRAX,DELZ
      COMMON R(150),Z(150),RB(150),ZB(150)
      COMMON DRB(150),DZB(150)
      COMMON M(2500)
      COMMON P(2500),U(2500),ETA(2500),V(2500),PSI(2500)
      COMMON DNORX(2500),DNORY(2500),PNORX(2500),PNORY(2500)
      COMMON DR,DZ
      COMMON NDEV1,NDEV2
      COMMON/FLAG1/FLAG1
      COMMON/MBTN/MBTN
      COMMON/FLGS/TTY,NDMP,NEDT,NSTP,NPIM
      COMMON/STUFF/ERRORS,NAME,DIVS,VCHM,UCHM
      COMMON/MOUSE/INX,INY,INSW,SWSTAT
      COMMON/LOOK/PMX,UMX,VMX,PMX1,UMX1,VMX1
      COMMON/HX/DTMAX
      LOGICAL TTY,NDMP,NEDT,NSTP,NPIM
      LOGICAL NFIB
      REAL MU
      INTEGER AND,OR,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     * FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,ARB
      DATA INTRF,CNTRB,SUR,FULL,EMP,BND,IN,OUT,
     * FRSLP,NOSLP,EMPBND,OB,COR,OK,GAS,ARB/1,2,4,8,16,32,
     * 64,128,256,512,1024,2048,4096,8192,16384,32768/
      DATA MASK1,MASK2,MASK3,MASK4,MASK5,MASK6,
     * MASK7,MASK8/0777777777757,0777777773777,
     * 0777777677777,0777777777773,0777777777767,
     * 0777777737777,0777777757777,0777777767777/
      INTEGER ES,EC
      DH=DR/2.
      EC=4112
      ES=4100
      KM=NA6
      K=NA7
      L=NA8
      IF(KM.NE.0)GO TO 95
      LMZ=LMAXZ
      KMZ=KMAXZ
      DO 100 L=2,LMZ
      KTT=(L-1)*KMAX
      DO 100 K=2,KMZ
      KM=KTT+K
      GO TO 96
95    LMZ=L
      KMZ=K
```

```
96          IF(M(KM+1).EQ.32.AND.M(KM).EQ.8)GO TO 98
            GO TO 99
98          U(KM)=0.
            V(KM+1)=-V(KM)
            GO TO 100
99          IF((M(KM).AND.OB).NE.OB)GO TO 100
            TAN=SIGN(DNORX(KM)/DNORY(KM),-DNORX(KM)*DNORY(KM))
            IF(DNORY(KM).EQ.0.0)TAN=10**20
            KT=KM+KMAX
            KB=KM-KMAX
            IF(M(KM+1).EQ.EC)GO TO 101
            IF(M(KM-1).EQ.EC)GO TO 102
            IF(M(KT).EQ.EC)GO TO 103
            IF(M(KB).EQ.EC)GO TO 104
            IF(M(KM+1).EQ.SC)GO TO 101
101         XU=(ZB(L)-PNORY(KM))/TAN+PNORX(KM)
            IF(M(KT).EQ.EC)GO TO 110
            IF(M(KB).EQ.EC)GO TO 111
            AL1=RB(K)-PNORX(KM)
            AL2=DR-AL1
            U(KM)=-(U(KM-1)*AL1)/AL2
            IF(TAN.GE.10**10)GO TO 112
            IF(((M(KT).AND.FULL).EQ.FULL).AND.(XU.GT.RB(K)))GO TO 114
            AL1=R(K)-XU
            AL2=DR-AL1
            V(KM)=-(V(KM-1)*AL1)/AL2
            GO TO 100
112         V(KM)=0.0
            GO TO 100
110         IF(ABS(TAN).LT.0.25)GO TO 103
            Y1=TAN*(R(K)-PNORX(KM))+PNORY(KM)
            YL=Y1-Z(L)
            XL=YL/TAN
            AL1=DH-XL
            AL2=DH+XL
            U(KM)=-(U(KM-1)*AL1)/AL2
            AL1=DH-YL
            AL2=DH+YL
            V(KM)=-(V(KB)*AL1)/AL2
            GO TO 100
111         Y1=TAN*(R(K)-PNORX(KM))+PNORY(KM)
            YL=Y1-Z(L)
            XL=YL/TAN
            AL1=DH+XL
            AL2=DH-XL
            U(KM)=-(U(KM-1)*AL1)/AL2
            IF(((M(KT).AND.OB).EQ.OB).AND.((M(KM-1).AND.FULL)
     *      .EQ.FULL))GO TO 115
            IF(((M(KM-1).AND.OB).EQ.OB).AND.((M(KT).AND.FULL)
     *      .EQ.FULL))GO TO 116
            AL1=DH+YL
            AL2=DH-YL
            V(KB)=-(V(KM)*AL1)/AL2
            GO TO 100
114         AL1=R(K+1)-XU
            AL2=DR-AL1
            V(KM+1)=-(V(KM)*AL1)/AL2
```

```
            GO TO 100
115         AL1=R(K)-XU
            AL2=DR-AL1
            V(KM)=-(V(KM-1)*AL1)/AL2
            GO TO 100
116         YR=TAN*(RB(K)-PNORX(KM))+PNORY(KM)
            AL1=YR-Z(L)
            AL2=DZ-AL1
            U(KM)=-(U(KT)*AL1)/AL2
            GO TO 100
102         XU=(ZB(L)-PNORY(KM))/TAN+PNORX(KM)
            IF(M(KB).EQ.EC)GO TO 120
            IF(M(KT).EQ.EC)GO TO 121
            AL1=PNORX(KM)-RB(K-1)
            AL2=DR-AL1
            U(KM-1)=-(U(KM)*AL1)/AL2
            AL1=XU-R(K)
            AL2=DR-AL1
            V(KM)=-(V(KM+1)*AL1)/AL2
            GO TO 100
120         Y1=TAN*(R(K)-PNORX(KM))+PNORY(KM)
            YL=Z(L)-Y1
            XL=YL/TAN
            AL1=DH+XL
            AL2=DH-XL
            U(KM-1)=-(U(KM)*AL1)/AL2
            AL1=DH-YL
            AL2=DH+YL
            V(KB)=-(V(KM)*AL1)/AL2
            GO TO 100
121         Y1=TAN*(R(K)-PNORX(KM))+PNORY(KM)
            YL=Z(L)-Y1
            XL=YL/TAN
            AL1=DH-XL
            AL2=DH+XL
            U(KM-1)=-(U(KM)*AL1)/AL2
            AL1=DH-YL
            AL2=DH+YL
            V(KM)=-(V(KB)*AL1)/AL2
            GO TO 100
103         YR=TAN*(RB(K)-PNORX(KM))+PNORY(KM)
            AL1=ZB(L)-PNORY(KM)
            AL2=DZ-AL1
            V(KM)=-(V(KB)*AL1)/AL2
            AL1=Z(L)-YR
            AL2=DZ-AL1
            U(KM)=-(U(KB)*AL1)/AL2
            GO TO 100
104         YR=TAN*(RB(K)-PNORX(KM))+PNORY(KM)
            AL1=PNORY(KM)-ZB(L-1)
            AL2=DZ-AL1
            V(KB)=-(V(KM)*AL1)/AL2
            AL1=YR-Z(L)
            AL2=DZ-AL1
            U(KM)=-(U(KT)*AL1)/AL2
            GO TO 100
100         CONTINUE
```

END

APPENDIX IV

SPY PROGRAM

Routine Name	Function
EXAMIN	Does display and interaction for Spy Program
SHARE	Sets up core-sharing process

```
            SUBROUTINE EXAMIN
            COMMON NVAC,NGEN,UAC,VAC,TM1,TM2,TM3
            COMMON NCYCLE,NSTOP,NEDTM,NEDIT,OPE
            COMMON TIME,EDTIM,EDDI,NPIT,NITER
            COMMON BETA,EPS2,DT,VMAX,UMAX,RELAX,CUT
            COMMON SMIN,EPS1,NBMAX,UBTO,VBTO,UBND,VBND
            COMMON UM,MU,RHOA,GR,GZ,G,ISEC
            COMMON VIN,UIN,DKP,DLP,NBP,DDR,DDZ
            COMMON NEXP,NEXPP,NPART,NDIV
            COMMON NGRID,KMAX,LMAX,KMAXZ,LMAXZ,KMAXZZ,LMAXZZ
            COMMON KDMN,LDMN,KDMX,LDMX,MESS(7)
            COMMON ICRT,XMAX,YMAX,CRTRA,CRTRB,CRTZA,CRTZB
            COMMON ITEST,IOZ,IZ,GAMA,PGAS,PGASZ,PAMB,GASV,GASVZ
            COMMON NF,NG,NIT,H,XG,HH,HV,GG,FUDGE,NTAL,CRAX,DELZ
            COMMON R(150),Z(150),RB(150),ZB(150)
            COMMON DRB(150),DZB(150)
            COMMON M(2500)
            COMMON P(2500),U(2500),ETA(2500),V(2500),PSI(2500)
            COMMON DNORX(2500),DNORY(2500),PNORX(2500),PNORY(2500)
            COMMON DR,DZ
            COMMON NDEV1,NDEV2
            COMMON/FLAG1/FLAG1
            COMMON/FLGS/TTY,NDMP,NEDT,NSTP,NPIM
            COMMON/STUFF/ERRORS,NAME,DIVS,PNORMS,TEMPS
            COMMON/MOUSE/INX,INY,INSW,SWSTAT
            COMMON/LOOK/PMX,UMX,VMX,PMX1,UMX1,VMX1
            DIMENSION IP1(70),IP2(70),IP3(70)
            LOGICAL TTY,NDMP,NEDT,NSTP,NPIM
            CALL FORK
            CALL SLTDIS
103         NIT=NITER/60*60
            NPLOTS=NITER
            NPLT1=NITER
1           CALL MOVETO(256,928)
            CALL WRITE('PREVIOUS CYCLE<>')
            CALL MOVETO(192,896)
            CALL WRITE('MAX PRESSURE=ΔΔΔΔΔ.ΔΔΔ<>',PMX)
            CALL MOVETO(192,864)
            CALL WRITE('MAX V-VELOCITY=ΔΔΔΔ.ΔΔΔ<>',VMX)
            CALL MOVETO(192,832)
            CALL WRITE('MAX U-VELOCITY=ΔΔΔΔ.ΔΔΔ<>',UMX)
            CALL MOVETO(256,768)
            CALL WRITE('THIS CYCLE<>')
            CALL MOVETO(192,736)
            CALL WRITE('MAX PRESSURE=ΔΔΔΔΔ.ΔΔΔ<>',PMX1)
            CALL MOVETO(192,704)
            CALL WRITE('MAX V-VELOCITY=ΔΔΔΔ.ΔΔΔ<>',VMX1)
            CALL MOVETO(192,672)
            CALL WRITE('MAX U-VELOCITY=ΔΔΔΔ.ΔΔΔ<>',UMX1)
            B=ALOG10(DIVS)
            IB=B+1
            D=ALOG10(ERRORS)
            ID=D+1
            CALL MOVETO(576,944)
            CALL WRITE('10<>')
            CALL MOVE(16,20)
            CALL WRITE('ΔΔ<>',IB)
```

```
        DO 3 J=1,4
        JPLT=544+J*100
        CALL MOVETO(592,JPLT)
3       CALL VEC(32,0)
        CALL MOVETO(576,464)
        CALL WRITE('10<>')
        CALL MOVE(16,20)
        CALL WRITE('ΔΔ<>',ID)
        DO 5 J=1,4
        JPLT=64+J*100
        CALL MOVETO(592,JPLT)
5       CALL VEC(32,0)
        CALL MOVETO(608,944)
        CALL VEC(0,-400)
        CALL VEC(352,0)
        CALL MOVETO(608,464)
        CALL VEC(0,-400)
        CALL VEC(352,0)
        CALL MOVETO(704,512)
        CALL WRITE('MAX DIVERGENCE<>')
        CALL MOVETO(704,32)
        CALL WRITE('ENORM/PNORM<>')
        CALL BOXES
        CALL MOVETO(186,56)
        CALL WRITE('SELECT<>')
        CALL MOVETO(170,152)
        CALL WRITE('DT=Δ.ΔΔΔΔΔΔ<>',DT)
        CALL MOVETO(170,248)
        CALL WRITE('NPIT<>')
        CALL WRITE(' =ΔΔΔ<>',NPIT)
        CALL MOVETO(128,344)
        CALL WRITE('BETA=ΔΔ.ΔΔΔΛΔ<>',BETA)
        CALL MOVETO(128,440)
        CALL WRITE('EPS=Δ.ΔΔΔΔΔΔΔ<>',EPS2)
        CALL MOVETO(427,480)
        CALL WRITE('CYCLE ΔΔΔΔ<>',NCYCLE)
        CALL SEND
        CALL MOVETO(430,448)
        CALL WRITE('ITER ΔΔΔΔ<>',NITER)
        CALL SEND
        ITLPT=0
6       IF(NITER.EQ.ITPLT)GO TO 7
        CALL DELETE
C       60 ITERATIONS CAN BE DISPLAYED ON SCOPE.....
        IF((NITER-NIT).GT.60)GO TO 103
        IY=544+(ALOG10(DIVS)-ID+4)*100
        IF(IY.GT.1000)IY=1000
        IF(IY.LT.544)IY=544
        IX=608+(NITER-NIT)*5
        IP2(NPLOTS-NIT)=IY
        CALL MOVETO(IX,IY)
        CALL VECTO(IX,544)
        IY=64+(ALOG10(ERRORS)-ID+4)*100
        IF(IY.LT.64)IY=64
        IP3(NPLOTS-NIT)=IY
        CALL MOVETO(IX,IY)
        CALL VECTO(IX,64)
```

```
                CALL APND
                CALL MOVETO(430,448)
                CALL WRITE('ITER ΔΔΔΔ<>',NITER)
                CALL APND
                NPLOTS=NPLOTS+1
                ITPLT=NITER
                IF(NITER.EQ.1)GO TO 103
7               CALL MSEINT(MBT)
                IF(MBT.EC.1)GO TO 8
                CALL SLEEP
                GO TO 6
8               CALL MOUSXY
                INY=(INY+96)/96
                GO TO (16,9,11,13,14),INY
9               TYPE 25
25              FORMAT(1H ,'DT=',$)
                ACCEPT 10,DT
10              FORMAT(F)
                GO TO 101
11              TYPE 12
12              FORMAT('NPIT=',$)
                ACCEPT 26,NPIT
26              FORMAT(I)
                GO TO 101
13              TYPE 24
24              FORMAT(1H ,'BETA=',$)
                ACCEPT 10,BETA
                RELAX=BETA*RHOA*DR**2/DT
                GO TO 101
14              TYPE 15
15              FORMAT(1H ,'EPS=',$)
                ACCEPT 10,EPS2
                GO TO 101
100             NIT=NIT+70
                NPLOTS=1
101             DO 102 I=NPLT1-NIT,NPLOTS-NIT-1
                IX=608+I*5
                IY=IP2(I)
                CALL MOVETO(IX,IY)
                CALL VECTO(IX,544)
                IY=IP3(I)
                CALL MOVETO(IX,IY)
102             CALL VECTO(IX,64)
                GO TO 1
16              CALL CLEAR
                CALL BOXES
                CALL MOVETO(186,56)
                CALL WRITE('STOP<>')
                CALL MOVETO(186,152)
                CALL WRITE('CYCLE<>')
                CALL MOVETO(186,248)
                CALL WRITE('PRINT<>')
                CALL MOVETO(186,344)
                CALL WRITE('DUMP<>')
                CALL MOVETO(186,440)
                CALL WRITE('EXIT<>')
                CALL SEND
```

```
            CALL WHOUSE
            INY=(INY+96)/96
            GO TO (17,18,19,20,21),INY
17          NSTP=.TRUE.
            CALL EXIT
18          NPIM=.TRUE.
            GO TO 101
19          NEDT=.TRUE.
            GO TO 101
20          NDMP=.TRUE.
            GO TO 101
23          FORMAT(I)
21          TYPE 26
26          FORMAT(1H ,'NDMP=',$)
            ACCEPT 23,NDMP1
            IF(NDMP1.NE.0)NDMP=NDMP1
            CALL EXIT
            END
            SUBROUTINE BOXES
            DO 1 I=1,5
            JPLT=(I-1)*96+32
            CALL MOVETO(96,JPLT)
1           CALL BOX
            RETURN
            END
            SUBROUTINE BOX
            CALL VEC(224,0)
            CALL VEC(0,64)
            CALL VEC(-224,0)
            CALL VEC(0,-64)
            RETURN
            END
```

```
        TITLE SHARE
            ENTRY FILE
            ENTRY FORK
FILE:       0
            HRROI    2,FNAME
            MOVSI    1,(1B1!1B17)
            GTJFN
            HALTF
            HRRZS    1
            MOVEM    1,FILJFN
            MOVE     2,[44B5!1B19!1B20!1B21!1B25!1B26]
            OPENF
            HALTF
            SETZ     5,
            MOVSI    3,(1B2!1B3!1B4)
            MOVSI    1,400000
FMAP:       HRRI     1,0(5)
            RPACS
            TLNN     2,(1B5)
            JRST     DONE
            MOVS     2,FILJFN
            HRRI     2,0(5)
            PMAP
            AOJA     5,FMAP
DONE:       MOVSI    1,(1B0)
            HRRI     1,FILJFN
            CLOSF
            JRA      16,0(16)
FORK:       0
            HRROI    2,FNAME
            MOVSI    1,(1B2!1B17)
            GTJFN
            HALTF
            HRRZS    1
            MOVEM    1,FILJFN
            MOVE     2,[44B5!1B19!1B20!1B21!1B25!1B26!]
            OPENF
            HALTF
            SETZ     5,
            MOVSI    3,(1B2!1B3!1B4)
            MOVS     1,FILJFN
FMAP1:      HRRI     1,0(5)
            RPACS
            TLNN     2,(1B5)
            JRST     DONE1
            MOVSI    2,400000
            HRRI     2,0(5)
            PMAP
            AOJA     5,FMAP1
DONE1:      MOVSI    1,(1B0)
            HRRI     1,FILJFN
            CLOSF
            JRA      16,0(16)
FNAME:      ASCIZ/EXAM+FILE.SHARE/
            END
```

APPENDIX V

OUTPUT PROGRAM

Routine Name	Function
MAIN	Read in data, compute A, BNDRY, and SI matrices. Controls other output functions.
CONTRL	Displays output functions
VPLOT	Draws velocity profiles
VVECT	Draws velocity vectors
CNTRL1	Displays axes for velocity profile
CNTRL2	Displays choices for contour plots
CONTOR	Contour plotting program

```
        INTEGER BLN(2),BNDRY
        DIMENSION UU(18,92),VV(18,92),PP(18,92),SI(18,92)
        DIMENSION BNDRY(18,92)
        DIMENSION A(18,92),U(2500),V(2500),P(2500)
        DIMENSION MESS(7)
        DIMENSION BPX(100),BPY(100)
        DIMENSION XB(100),YB(100),NSEQ(100)
        DIMENSION XBP(50,2),YBP(50,2)
        DIMENSION M(2500)
        DIMENSION R(150),Z(150),RB(150),ZB(150)
        DIMENSION XBB(50,2),YBB(50,2)
        DIMENSION ME(18,92)
        DIMENSION US(300)
        DIMENSION PTX(300),PTY(300),ZNP(300),ZMP(300),RMP(300),RNP(300)
        EQUIVALENCE (ME,M)
        EQUIVALENCE(XBB,XBP),(YBB,YBP)
        EQUIVALENCE(U,UU),(V,VV),(P,PP)
        COMMON/CLP/IN,IXP,IYP,MN
        COMMON/MOUSE/INX,INY,INSW,SWSTAT
        COMMON/STUFF/DR,DZ,KMAX,LMAX,KDMN,LDMN,KDMX,LDMX,EPS1,DT
        COMMON/WINDOW/WS,WCX,WCY,XL
        COMMON/CONLVL/NCLS,NCL
        COMMON/BOUN/BLN,XBP,YBP
        INTEGER EMP,BND,FULL,OB
        DATA EMP,BND,FULL,OB/16,32,8,2048/
        WS=8.0
        WCX=8.0
        NYS='N'
        WCY=8.0
105     TYPE 1001
1001    FORMAT(1H ,'DISPLAY=',$)
        ACCEPT 101,IDI
101     FORMAT(A4)
        TYPE 102
102     FORMAT(1H ,'INPUT FILE=',$)
        ACCEPT 103,NAME
103     FORMAT(A5)
        IF(IDI.EQ.'ARDS')IDI=1
        IF(IDI.EQ.'1559')IDI=2
        NAME=NAME+32
        CALL IFILE(22,NAME)
        READ(22,1)(MESS(I),I=1,7)
1       FORMAT(7A5)
        READ(22,2)KMAX,LMAX
2       FORMAT(2I)
        READ(22,3)SMIN,EPS1
3       FORMAT(2F)
        READ(22,4)D,D,MU,RHOA
4       FORMAT(4F)
        READ(22,5)DR
5       FORMAT(F)
        READ(22,5)DZ
        READ(22,6)D
6       FORMAT(I)
        READ(22,3)BPX(1),BPY(1)
        MM=2
7       READ(22,3)BPX(MM),BPY(MM)
```

```
        IF(BPX(1).EQ.BPX(MM).AND.BPY(1).EQ.BPY(MM))GO TO 8
        MM=MM+1
        GO TO 7
8       MM=MM-1
        DO 9 I=1,6
9       READ(22,6)U
        N=1
10      READ(22,11)XB(N),YB(N),NSEQ(N)
11      FORMAT(2F,I)
        IF(NSEQ(N).EQ.1)GO TO 12
        N=N+1
        GO TO 10
12      KMAXZZ=KMAX-2
        LMAXZZ=LMAX-2
        KMAXZ=KMAX-1
        LMAXZ=LMAX-1
        XBMAX=DR*KMAXZZ
        YBMAX=DZ*LMAXZZ
        N=0
        MM=0
13      N=N+1
        MM=MM+1
        XBP(MM,1)=YB(N)
        YBP(MM,1)=XB(N)
        IF(NSEQ(N).EQ.0)GO TO 13
        XBP(MM,1)=YB(N)
        YBP(MM,1)=XB(N)
        MM=MM+1
        XBP(MM,1)=YBMAX
        YBP(MM,1)=XBMAX
        BLN(1)=MM
        MM=0
14      MM=MM+1
        N=N+1
        XBP(MM,2)=YB(N)
        YBP(MM,2)=XB(N)
        IF(NSEQ(N).EQ.1)GO TO 15
        GO TO 14
15      XBP(MM,2)=YB(N)
        YBP(MM,2)=XB(N)
        BLN(2)=MM
        NAME=NAME+6
        CALL IFILE(23,NAME)
        READ(23)M
        READ(23)U,V,P
        READ(23)DT,RHOA,TIME,NCYCLE,MU,EPS1
        READ(23)KDMN,KDMX,LDMN,LDMX,DR,DZ,KMAX,LMAX
        KMAXZ=KMAX-1
        LMAXZ=LMAX-1
        KMAXZZ=KMAX-2
        LMAXZZ=LMAX-2
        DO 414 I=1,KMAX
        DO 414 J=1,LMAX
414     BNDRY(I,J)=2
        DO 411 L=2,LMAXZ
        NBND=1
        IF((ME(2,L).AND.EMP).EQ.EMP)GO TO 401
```

```
        IF((ME(2,L).AND.FULL).NE.FULL)GO TO 399
        NBND=2
399     BNDRY(1,L)=1
        GO TO 402
401     BNDRY(1,L)=2
402     DO 411 K=2,KMAX
        GO TO (403,405,407,409,411),NBND
403     IF((ME(K,L).AND.OB).EQ.OB)GO TO 404
        BNDRY(K,L)=2
        GO TO 411
404     BNDRY(K,L)=1
        NBND=2
        GO TO 411
405     IF((ME(K,L).AND.OB).NE.OB)GO TO 406
        BNDRY(K,L)=1
        NBND=3
        GO TO 411
406     BNDRY(K,L)=0
        NBND=3
        GO TO 411
407     IF((ME(K,L).AND.OB).EQ.OB.OR.(ME(K,L).AND.BND).EQ.BND)
     *  GO TO 408
        BNDRY(K,L)=0
        GO TO 411
408     BNDRY(K,L)=1
        NBND=4
        GO TO 411
409     IF((ME(K,L).AND.OB).EQ.OB.OR.(ME(K,L).AND.BND).EQ.BND)
     *  GO TO 410
        BNDRY(K,L)=2
        NBND=5
        GO TO 411
410     BNDRY(K,L)=1
        NBND=5
411     CONTINUE
        DO 412 K=1,KMAX
        IF((ME(K,1).AND.BND).NE.BND)GO TO 412
        BNDRY(K,1)=1
        IF((ME(K,LMAX).AND.BND).NE.BND)GO TO 412
        BNDRY(K,LMAX)=1
412     CONTINUE
        DO 413 K=1,KMAX
413     IF(BNDRY(K,2).EQ.2)BNDRY(K,1)=2
        IF(NYS.EQ.'N')GO TO 303
        TYPE 299
299     FORMAT(1H ,'ABMAC CALCULATION FOR PLOT ROUTINES')
        DO 301 L=1,LMAX
303     RB(1)=1./10.**10
        ZB(1)=0.
        KMAXZ=KMAX-1
        LMAXZ=LMAX-1
        DO 415 I=1,KMAXZ
415     RB(I+1)=RB(I)+DR
        DO 416 I=1,LMAXZ
416     ZB(I+1)=ZB(I)+DR
        DO 417 I=1,KMAX
        DO 417 J=1,LMAX
```

```
417        A(I,J)=DR
           DO 100 J=1,2
           NBMAX=BLN(J)-1
           ISEC=0
           DO 32 I=1,NBMAX
           IF(YBB(I+1,J)-YBB(I,J))20,24,16
16         L1=(YBB(I,J)+.000001)/DZ+2
           AA=(XBB(I+1,J)-XBB(I,J))/(YBB(I+1,J)-YBB(I,J))
           L2=LMAX
           B=XBB(I,J)-AA*YBB(I,J)
           LDL=1
           N=0
           DO 18 L=L1,L2,LDL
           IF(ZB(L)-YBB(I+1,J)-.000001)17,17,19
17         N=N+1
           ZMP(N)=ZB(L)
18         RMP(N)=AA*ZMP(N)+B
19         LLINE=N
           GO TO 25
20         L1=(YBB(I,J)-.000001)/DZ+1
           AA=(XBB(I+1,J)-XBB(I,J))/(YBB(I+1,J)-YBB(I,J))
           L2=1
           B=XBB(I,J)-AA*YBB(I,J)
           LDL=-1
           N=0
           DO 22 L=L1,L2,LDL
           IF(ZB(L)-YBB(I+1,J)+.000001)23,21,21
21         N=N+1
           ZMP(N)=ZB(L)
22         RMP(N)=ZMP(N)*AA+B
23         LLINE=N
           GO TO 25
24         LLINE=0
25         CONTINUE
           JMAX=LLINE
           DO 27 KJ=1,JMAX
27         DS(KJ)=(RMP(KJ)-XBB(I,J))**2+(ZMP(KJ)-YBB(I,J))**2
           DO 30 N=1,JMAX
           TEST=10.0**5
           MTRANS=0
           DO 29 MM=1,JMAX
           IF(DS(MM)-TEST)28,28,29
28         TEST=DS(MM)
           MTRANS=MM
29         CONTINUE
           RNP(N)=RMP(MTRANS)
           ZNP(N)=ZMP(MTRANS)
           DS(MTRANS)=10.0**7
30         CONTINUE
           J1=ISEC+1
           J2=ISEC+JMAX
           N=0
           DO 31 KJ=J1,J2
           N=N+1
           PTX(KJ)=RMP(N)
           PTY(KJ)=ZNP(N)
31         CONTINUE
```

```
         ISEC=ISEC+JMAX
32       CONTINUE
         I=1
33       I=I+1
34       IF(ABS(PTX(I)-PTX(I-1))-DEPSX)35,35,38
35       IF(ABS(PTY(I)-PTY(I-1))-DEPSY)36,36,38
36       ISEC=ISEC-1
         DO 37 KJ=I,ISEC
         PTX(KJ)=PTX(J+1)
         PTY(KJ)=FTY(J+1)
37       CONTINUE
         IF(I-ISEC)34,34,39
38       IF(I-ISEC)33,39,39
39       CONTINUE
         ISECZ=ISEC-1
         DEP=(PTX(ISEC)-PTX(ISECZ))**2+(PTY(ISEC)-PTY(ISECZ))**2
         DEP=SQRT(DEP)
         IF(DEP-.2*DR)41,42,42
41       ISEC=ISECZ
42       CONTINUE
         DEP=(PTX(2)-PTX(1))**2+(PTY(2)-PTY(1))**2
         DEP=SQRT(DEP)
         L=ISEC
         IF(NYS.EQ.'N')GO TO 54
         TYPE 53
53       FORMAT(1H ,////,' BOUNDARY-MESH INTERSECTIONS')
         DO 51 K=1,L
51       TYPE 52,K,PTX(K),K,PTY(K)
52       FORMAT(1H ,'PTX(',I2,')=',F,' PTY(',I2,')=',F)
54       DO 50 K=1,L
         II=(PTX(K)+.001)/DR+2
         JJ=(PTY(K)+.001)/DZ+2
         X1=PTX(K)-FLOAT(II-2)*DR
         Y1=PTY(K)-FLOAT(JJ-2)*DZ
         IF(X1.GT..000001)GO TO 47
         IF(Y1.LT.00005.OR.Y1.GT.0.199990)GO TO 49
         IF(BNDRY(II,JJ).EQ.1)GO TO 46
         A(II,JJ+1)=Y1
46       A(II,JJ)=DR-Y1
         GO TO 49
47       IF(X1.GE..19998)GO TO 49
         IF(BNDRY(II,JJ).EQ.1)A(II,JJ)=DR-X1
         IF(BNDRY(II+1,JJ).EQ.1)A(II+1,JJ)=X1
         IF(BNDRY(II-1,JJ).EQ.1)A(II-1,JJ)=DR+X1
1721     FORMAT(1H ,2I,F,I)
49       CONTINUE
50       CONTINUE
100      CONTINUE
         IF(NYS.EQ.'N')GO TO 312
         DO 310 K=1,KMAX
         DO 310 L=1,LMAX
         IF(ABS(A(K,L)-0.2).LE.0.0001)GO TO 310
310      CONTINUE
312      CONTINUE
         DO 915 L=1,LMAX
         SI(1,L)=0.5
         NBND=0
```

```
        IF(BNDRY(1,L).EQ.1)NBND=1
        DO 914 K=2,KMAX
        IF(NBND.GT.0)GO TO 912
        IF(BNDRY(K,L).EQ.1)NBND=1
911     SI(K,L)=0.5
        GO TO 914
912     IF(BNDRY(K,L).EQ.0)NBND=2
        IF(NBND.EQ.2.AND.BNDRY(K,L).EQ.2)GO TO 915
        SI(K,L)=SI(K-1,L)-0.5*A(K-1,L)*
     *  (VV(K,L)*RB(K)+VV(K-1,L)*RB(K-1))
914     CONTINUE
915     CONTINUE
900     CALL SETDIS
        CALL RECT1(6)
        CALL CONTRL
        CALL SEND
        IF(IDI.EQ.1)CALL AMOUSE
        IF(ID1.EQ.2)CALL WMOUSE
        INY=(INY+128)/128
        GO TO (106,107,109,111,108,111),INY
106     CALL EXIT
107     GO TO 105
108     CONTINUE
201     CALL CHGBIN
        CALL CLEAR
        CALL CNTRL1
200     CALL VPLOT(V)
        IF(IDI.EQ.1)CALL AMOUSE
        IF(IDI.EQ.2)CALL WMOUSE
        INY=(INY+128)/128
        GO TO (900,200,201),INY
109     CALL CHGBIN
        CALL CLEAR
        RB(1)=1./10.**10
        DO 309 K=1,KMAXZ
309     RB(K+1)=RB(K)+DR
        ZB(1)=0.
        DO 306 L=1,LMAXZ
306     ZB(L+1)=ZB(L)+DZ
        R(1)=-0.5*RB(2)
        Z(1)=-.05*ZB(2)
        DO 307 K=2,KMAX
307     R(K)=(RB(K)+RB(K-1))*.5
        DO 308 L=2,LMAX
308     Z(L)=(ZB(L)+ZB(L-1))*.5
        CALL VVECT(U,V,R,Z,M)
        CALL SEND
        IF(IDI.EQ.1)CALL AMOUSE
        IF(IDI.EQ.2)CALL WMOUSE
        INY=(INY+128)/128
        GO TO (900,300),INY
300     CALL CHGBIN
        CALL MOVETO(0,1000)
        CALL SEND
        CALL CHGASC
        TYPE 301
301     FORMAT(1H ,'WS=',$)
```

```
              ACCEPT 302,WS
302           FORMAT(F)
              TYPE 357
357           FORMAT(1H ,'WCX=',$)
              ACCEPT 304,WCX
304           FORMAT(F)
              TYPE 305
305           FORMAT(1H ,'WCY=',$)
              ACCEPT 304,WCY
              CALL CHGBIN
              GO TO 109
110           CONTINUE
111           CALL CLEAR
              SC=700/((LMAXZ-2)*DZ)
              CALL CNTRL2
              CALL WMOUSE
              INYGT=(INY+128)/128
              IF(INYGT.EQ.5)GO TO 900
              TYPE 113
113           FORMAT(1H ,'DEFINE REGION OF INTEREST')
              CALL WMOUSE
              WCX=(INX-128)/SC
              WCY=(INY-380)/SC+XL
              CALL WMOUSE
              WS=WCX-(INX-128)/SC
              TYPE 114
114           FORMAT(1H ,'POSITIVE CONTOUR LEVELS=',$)
              ACCEPT 115,NCLS
115           FORMAT(I)
              TYPE 116
116           FORMAT(1H ,'NEGATIVE CONTOUR LEVELS=',$)
              ACCEPT 115,NCL
              XL=0
              XW=0
              DO 117 I=1,BLN(1)
117           IF(YBP(I,1).GT.XL)XL=YBP(I,1)
              DO 121 J=1,2
              DO 119 I=1,BLN(J)
              IX=1023/2*(1+(XBP(I,J)-WCX)/WS)
              IY=1023/2*(1+(YBP(I,J)-WCY+XL)/WS)
              IF(I.EQ.1)GO TO 118
              CALL VECLP(IX,IY)
              GO TO 119
118           CALL MOVCLP(IX,IY)
              IONE=1
119           CONTINUE
              DO 121 I=1,BLN(J)
              IX=1023/2*(1+(XBP(I,J)-WCX)/WS)
              IY=1023/2*(1+(XL-YBP(I,J)-WCY)/WS)
              IF(I.EQ.1)GO TO 120
              CALL VECLP(IX,IY)
              GO TO 121
120           CALL MOVCLP(IX,IY)
121           CONTINUE
              CALL SEND
              GO TO (122,123,124,125,900),INYGT
122           CALL CONTOR(18,92,5.,VV,BNDRY,A,18,82)
```

```
                GO TO 126
123             CALL CONTOR(18,92,5.,UU,BNDRY,A,18,92)
                GO TO 126
124             CALL CONTOR(18,92,5.,PP,BNDRY,A,18,92)
                GO TO 126
125             CONTINUE
                XX=LMAX*DZ-DZ
                IMX=BLN(2)
                IX=1023/2*(1+(-WCX)/WS)
                IY=1023/2*(1+(XL-WCY)/WS)
                CALL MOVCLP(IX,IY)
                IX=1023/2*(1+(XBP(IMX,2)-WCX)/WS)
                CALL VECLP(IX,IY)
                IX=1023/2*(1+(XBP(1,2)-WCX)/WS)
                CALL MOVCLP(IX,IY)
                IX=1023/2*(1+(XX-WCX)/WS)
                CALL VECLP(IX,IY)
                CALL APND
                CALL CONTOR(18,92,5.,SI,BNDRY,A,18,92)
126             CALL APND
                CALL WMOUSE
                GO TO 111
                GO TO 900
                END
                SUBROUTINE RECT1(N)
                DO 10 I=1,N
                JPOS=(I*128)-128
                CALL MOVETO(704,JPOS)
10              CALL RECT
                RETURN
                END
                SUBROUTINE RECT
                CALL VEC(0,64)
                CALL VEC(192,0)
                CALL VEC(0,-64)
                CALL VEC(-192,0)
                RETURN
                END
                SUBROUTINE AMOUSE
                COMMON/MOUSE/INX,INY,INSW,SWSTAT
                CALL CHGASC
                TYPE 10
10              FORMAT(1H ,'*')
                ACCEPT 11,INY
11              FORMAT(I)
                INSW=INY
                INY=INY*128-128
                RETURN
                END
                SUBROUTINE CONTRL
                CALL MOVETO(770,24)
                CALL WRITE('STOP<>')
                CALL MOVETO(746,152)
                CALL WRITE('NEW DATA<>')
                CALL MOVETO(752,264)
                CALL WRITE('VECTORS<>')
                CALL MOVETO(746,296)
```

```
        CALL WRITE('VELOCITY<>')
        CALL MOVETO(722,408)
        CALL WRITE('CONTOUR PLOT<>')
        CALL MOVETO(746,520)
        CALL WRITE('PROFILES<>')
        CALL MOVETO(746,552)
        CALL WRITE('VELOCITY<>')
        CALL MOVETO(710,664)
        CALL WRITE('ISOMETRIC PLOT<>')
        CALL MOVETO(900,24)
        CALL WRITE('1<>')
        CALL MOVETO(900,152)
        CALL WRITE('2<>')
        CALL MOVETO(900,280)
        CALL WRITE('3<>')
        CALL MOVETO(900,408)
        CALL WRITE('4<>')
        CALL MOVETO(900,536)
        CALL WRITE('5<>')
        CALL MOVETO(900,664)
        CALL WRITE('6<>')
        RETURN
        END
        SUBROUTINE VPLOT(V)
        COMMON/WINDOW/WS,WCX,WCY,XL
        COMMON/STUFF/DR,DZ,KMAX,SZF
        COMMON/MOUSE/INX,INY,INSW,SWTAT
        DIMENSION V(2500)
        DIMENSION PV(50)
        KMAXZ=KMAX-1
        CALL CHGBIN
        CALL MOVETO(0,1000)
        CALL CHGASC
        TYPE 3
3       FORMAT(1H ,'PROFILE AT Z=',$)
        ACCEPT 4,PZ
        LPOS=200+(PZ*190)/((KMAX-2)*2*DR)-5
        CALL MOVETO(LPOS,820)
        CALL VEC(-10,0)
        CALL VEC(5,15)
        CALL VEC(5,-15)
4       FORMAT(F)
        L=PZ/DZ+1
        KTT=(L-1)*KMAX
        DO 6 K=1,KMAX
        KM=KTT+K
        PV(K+KMAX)=V(KM)
6       PV(KMAX-K+1)=V(KM)
        SC=350/(KMAX-2)
        MOVE=0
        DO 7 K=2,KMAX
        IF(PV(K)+10.00000.LT..0001)GO TO 7
        GO TO 8
7       CONTINUE
8       KST=K-1
        PV(KST)=0.
        KND=KMAX*2-KST+1
```

```
         PV(KNU)=0.
12       DO 13 K=KST,KNU
         IX=K*SC+120
         IY=-10.*PV(K)+128
         IF(MOVE.EQ.0)CALL MOVETO(IX,IY)
         CALL ZIPTO(IX,IY)
13       MOVE=1
         CALL APND
         RETURN
         END
         SUBROUTINE VVECT(U,V,R,Z,M)
         DIMENSION U(2500),V(2500),M(2500),R(150),Z(150)
         COMMON/MOUSE/INX,INY,INSW,SWSTAT
         COMMON/WINDOW/WS,WCX,WCY,XL
         COMMON/STUFF/DR,DZ,KMAX,SZF,KDMN,LDMN,KDMX,LDMX,EPS1,DT
         COMMON/BOUN/BLN(2),XBP(50,2),YB (50,2)
         INTEGER BLN
         INTEGER FULL,SUR
         DATA FULL,SUR/8,4/
         DO 311 J=1,2
         DO 312 I=1,BLN(J)
         IX=1023/2*(1+(XBP(I,J)-WCX)/WS)
         IY=1023/2*(1+(YBP(I,J)-WCY+XL)/WS)
         IF(I.EQ.1)GO TO 345
         CALL VECLP(IX,IY+512)
         GO TO 312
345      CALL MOVCLP(IX,IY+512)
312      CONTINUE
         DO 313 I=1,BLN(J)
         IX=1023/2*(1+(XBP(I,J)-WCX)/WS)
         IY=1023/2*(1+(XL-YBP(I,J)-WCY)/WS)
         IF(1.EQ.1)GO TO 355
         CALL VECLP(IX,IY+512)
         GO TO 313
355      CALL MOVCLP(IX,IY+512)
313      CONTINUE
311      CONTINUE
         KKK=.5*(2.+KDMN)+.5*ABS(2.-KDMN)
         LLL=.5*(2.+LDMN)+.5*ABS(2.-LDMN)
         IONE=1
26       DO 375 K=KKK,KDMX
         DO 375 L=LLL,LDMX
         KM=K+(L-1)*KMAX
         KB=KM-KMAX
         IF(((M(KM).AND.SUR).EQ.SUR).OR.((M(KM).AND.FULL).EQ.FULL))
     *   GO TO 203
         GO TO 375
203      V1=.5*(V(KM)+V(KB))
         U1=.5*(U(KM)+U(KM-1))
         IF(ABS(U1)-.001)41,41,40
41       IF(ABS(V1)-.001)375,375,40
40       R1=R(K)
         Z1=Z(L)
         R2=R1+2.*DT*U1*DR/EPS1
         Z2=Z1+2.*DT*V1*DZ/EPS1
         R1=IONE*R1
         R2=IONE*R2
```

```fortran
      R1=R1+XL
      R2=R2+XL
      IX1=1023/2*(1+(Z1-WCX)/WS)
      IX2=1023/2*(1+(Z2-WCX)/WS)
      IY1=512+1023/2*(1+(R1-WCY)/WS)
      IY2=512+1023/2*(1+(R2-WCY)/WS)
      IF((IX1-IX2.LE.1).AND.(IY1-IY2.LE.1))GO TO 375
      CALL MOVCLP(IX1,IY1)
      CALL VECLP(IX2,IY2)
      GO TO 375
375   CONTINUE
      IF(IONE.NE.1)GO TO 452
      IONE=-1
      GO TO 26
452   RETURN
      END
      SUBROUTINE CNTRL1
      COMMON/MOUSE/INX,INY,INSW,SWSTAT
      COMMON/STUFF/DR,DZ,KMAX
      COMMON/BOUN/BLN(2),XBP(50,2),YBP(50,2)
      INTEGER BLN
      CALL MOVETO(120,512)
      CALL VECTO(120,116)
      CALL MOVETO(108,128)
      CALL VECTO(820,128)
      DO 1 J=1,4
      JPOS=128+J*100
      JN=J*10
      CALL MOVETO(120,JPOS)
      CALL VEC(-12,0)
      CALL MOVE(-30,-3)
      CALL WRITE('∆∆.<>',JN)
1     CONTINUE
      DO 2 I=1,4
      IPOS=120+I*175
      IN=-32+I*16
      CALL MOVETO(IPOS,128)
      CALL VEC(0,-12)
      CALL MOVE(-12,-16)
2     CALL WRITE('∆∆∆.<>',IN)
      CALL MOVETO(340,48)
      CALL WRITE('RADIAL POSITION (MM)<>')
      CALL MOVETO(32,512)
      CALL WRITE('A<>')
      CALL MOVETO(32,492)
      CALL WRITE('X<>')
      CALL MOVETO(32,472)
      CALL WRITE('I<>')
      CALL MOVETO(32,452)
      CALL WRITE('A<>')
      CALL MOVETO(32,432)
      CALL WRITE('L<>')
      CALL MOVETO(32,392)
      CALL WRITE('V<>')
      CALL MOVETO(32,372)
      CALL WRITE('E<>')
      CALL MOVETO(32,352)
```

```
            CALL WRITE('L<>')
            CALL MOVETO(32,332)
            CALL WRITE('O<>')
            CALL MOVETO(32,312)
            CALL WRITE('C<>')
            CALL MOVETO(32,292)
            CALL WRITE('I<>')
            CALL MOVETO(32,272)
            CALL WRITE('T<>')
            CALL MOVETO(32,252)
            CALL WRITE('Y<>')
            CALL MOVETO(32,212)
            CALL WRITE('C<>')
            CALL MOVETO(32,192)
            CALL WRITE('M<>')
            CALL MOVETO(32,172)
            CALL WRITE('/<>')
            CALL MOVETO(32,152)
            CALL WRITE('S<>')
            CALL MOVETO(32,132)
            CALL WRITE('E<>')
            CALL MOVETO(32,112)
            CALL WRITE('C<>')
            SC=190/((KMAX-2)*DR*2)
            DO 7 J=1,2
            DO 4 I=1,BLN(J)
            IX=XBP(I,J)*SC
            IY=YBP(I,J)*SC
            IF(I.EQ.1)GO TO 3
            CALL VECTO(IX+200,927+IY)
            GO TO 4
3           CALL MOVETO(IX+200,927+IY)
4           CONTINUE
            DO 6 I=1,BLN(J)
            IX=XBP(I,J)*SC
            IY=YBP(I,J)*SC
            IF(I.EQ.1)GO TO 5
            CALL VECTO(IX+200,927-IY)
            GO TO 6
5           CALL MOVETO(IX+200,927-IY)
6           CONTINUE
7           CONTINUE
            CALL MOVETO(416,800)
            CALL WRITE('AXIAL POSITION<>')
            CALL MOVETO(886,24)
            CALL WRITE('RETURN<>')
            CALL MOVETO(886,152)
            CALL WRITE('OVERLAY<>')
            CALL MOVETO(896,280)
            CALL WRITE('CLEAR<>')
            CALL SEND
452         RETURN
            END
            SUBROUTINE CNTRL2
            COMMON/MOUSE/INX,INY,INSW,SWSTAT
            COMMON/STUFF/DR,DZ,KMAX,LMAX
            COMMON/BOUN/BLN(2),XBP(50,2),YBP(50,2)
```

```
        INTEGER BLN
        CALL MOVETO(868,24)
        CALL WRITE('V-VELOCITY<>')
        CALL MOVETO(868,152)
        CALL WRITE('U-VELOCITY<>')
        CALL MOVETO(868,280)
        CALL WRITE('PRESSURE<>')
        CALL MOVETO(874,396)
        CALL WRITE('FUNCTION<>')
        CALL MOVETO(886,422)
        CALL WRITE('STREAM<>')
        SC=700/((LMAX-2)*DZ)
        DO 5 J=1,2
        DO 2 I=1,BLN(J)
        IX=XBP(I,J)*SC+128
        IY=YBP(I,J)*SC+380
        IF(I.EQ.1)GO TO 1
        CALL VECTO(IX,IY)
        GO TO 2
  1     CALL MOVETO(IX,IY)
  2     CONTINUE
        DO 4 I=1,BLN(J)
        IX=XBP(I,J)*SC+128
        IY=380-YBP(I,J)*SC
        IF(I.EQ.1)GO TO 3
        CALL VECTO(IX,IY)
        GO TO 4
  3     CALL MOVETO(IX,IY)
  4     CONTINUE
  5     CONTINUE
        CALL SEND
        RETURN
        END
```

```
      SUBROUTINE CONTOR(M,N,XDIS,G,BND,A,MD,ND)
      DIMENSION G(MD,ND)
      DIMENSION XX(5),YY(5),B(200),X(200),
     * Y(200),BND(MD,ND),A(MD,ND),F(5),S(5),T(5)
      DIMENSION XS(8000),YS(8000),XP(300),YP(300)
      COMMON/WINDOW/WS,WCX,WCY,XL
      COMMON/CONLVL/NCLS,NCL
      INTEGER BND
      SCALE=XDIS/FLOAT(M-1)
      G1=G(1,1)
      G2=G1
      DO 66 I=1,M
      DO 66 J=1,N
      IF(BND(I,J).GT.1)GO TO 66
      G1=AMIN1(G1,G(I,J))
      G2=AMAX1(G2,G(I,J))
66    CONTINUE
      NCL1=NCLS
      TEMP=G1
      G1=0.0
      GS=(G2-G1)/FLOAT(NCL1+1)
      B(1)=G1+GS
      DO 67 K=2,NCL1
67    B(K)=B(K-1)+GS
      G1=TEMP
      IF(G1.GE.0.0)GO TO 68
      TST=-G1/(NCL+1)
      NCL1=NCL+NCLS
      NCLN=NCLS+2
      B(NCLS+1)=G1+TST
      DO 69 K=NCLN,NCL1
69    B(K)=B(K-1)+TST
68    CALL CHGBIN
      CALL MOVETO(0,1000)
      CALL APND
      TYPE 70,G1,G2,(B(K),K=1,NCL1)
70    FORMAT(1H ,10X,'MIN GRID VALUE=',F,3X,
     * 'MAX GRID VALUE= ',F,/1H ,10X,'CONTOUR LEVELS'/
     * (10X,4F))
      CALL CHGBIN
      DO 1 I=1,100
      X(I)=(I-1)*.2
1     Y(I)=(I-1)*.2
      M1=M-1
      N1=N-1
      LS=0
      DO 44 I=1,M1
      NS=1
2     JTEMP=1
      DO 5 J=NS,N1
      GO TO (3,4),JTEMP
3     IF(BND(I,J+1).GE.1.AND.BND(I+1,J+1).GE.1)GO TO 5
      NB=J
      JTEMP=2
      GO TO 5
4     IF(BND(I,J+1).EQ.0.OR.BND(I+1,J+1).EQ.0)GO TO 5
      NF=J
```

```
          NS=J+1
          IF(NS.GT.N)NS=N
          GO TO 6
    5     CONTINUE
          GO TO 44
    6     DO 43 J=NB,NF
          ICL=1
          IS=0
          IF(BND(I,J).GE.1)IS=IS+6
          IF(BND(I,J+1).GE.1)IS=IS+2
          IF(BND(I+1,J+1).GE.1)IS=IS+3
          IF(BND(I+1,J).GE.1)IS=IS+4
          IF(A(I+1,J)-1.)11,7,11
    7     IF(A(I,J)-1.)11,8,11
    8     IF(A(I+1,J+1)-1.)11,9,11
    9     IF(A(I+1,J)-1.)11,10,11
   10     IF(BND(I,J).EQ.2.OR.BND(I,J+1).EQ.2.OR.BND(I+1,J+1).
      *   EQ.2.OR.BND(I+1,J).EQ.2)GO TO 11
          IS=1
          GO TO 13
   11     IF(IS.GE.1.AND.IS.LE.15)GO TO 13
          IS=1
          KKKKK=KKKKK+1
          IF(KKKKK.GT.40)GO TO 13
          IF(ISEE.EQ.1)TYPE 12,I,J
   12     FORMAT(1H ,20X,31HWARNING... 'IS' IS OUT OF RANGE,
      *   3X,2HI=I3,3X,2HJ=I3)
   13     F(1)=G(I,J)
          F(2)=G(I,J+1)
          F(3)=G(I+1,J+1)
          F(4)=G(I+1,J)
          S(1)=X(I)
          S(2)=X(I)
          S(3)=X(I+1)
          S(4)=X(I+1)
          T(1)=Y(J)
          T(2)=Y(J+1)
          T(3)=Y(J+1)
          T(4)=Y(J)
          IN=4
          GO TO (28,14,15,16,17,18,19,20,26,21,27,24,23,43,43),IS
   14     F(2)=G(I,J+1)
          F(3)=G(I,J+1)
          F(4)=G(I+1,J+1)
          F(5)=G(I+1,J)
          S(3)=X(I+1)-A(I,J+1)
          S(5)=X(I+1)
          T(2)=Y(J)+A(I,J+1)
          T(4)=Y(J+1)
          T(5)=Y(J)
          IN=5
          GO TO 28
   15     F(3)=G(I+1,J+1)
          F(4)=G(I+1,J+1)
          F(5)=G(I+1,J)
          S(3)=X(I)+A(I+1,J+1)
          S(5)=X(I+1)
```

```
            T(4)=Y(J)+A(I+1,J+1)
            T(5)=Y(J)
            IN=5
            GO TO 28
16          F(4)=G(I+1,J)
            F(5)=G(I+1,J)
            S(5)=X(I)+A(I+1,J)
            T(4)=Y(J+1)-A(I+1,J)
            T(5)=Y(J)
            IN=5
            GO TO 28
17          F(2)=G(I,J+1)
            F(3)=G(I+1,J+1)
            T(2)=Y(J)+A(I,J+1)
            T(3)=Y(J)+A(I+1,J+1)
            IN=4
            GO TO 28
18          IF(BND(I,J+1).GE.1.AND.BND(I+1,J).GE.1)GO TO 25
            F(1)=G(I,J)
            F(5)=G(I,J)
            S(5)=X(I+1)-A(I,J)
            T(1)=Y(J+1)-A(I,J)
            T(5)=Y(J)
            IN=5
            GO TO 28
19          F(3)=G(I+1,J+1)
            F(4)=G(I+1,J)
            S(3)=X(I)+A(I+1,J+1)
            S(4)=X(I)+A(I+1,J)
            IN=4
            GO TO 28
20          F(1)=G(I,J)
            F(2)=G(I,J+1)
            S(1)=X(I+1)-A(I,J)
            S(2)=X(I+1)-A(I,J+1)
            IN=4
            GO TO 28
21          F(1)=G(I,J)
            F(4)=G(I+1,J)
            T(1)=Y(J+1)-A(I,J)
            T(4)=Y(J+1)-A(I+1,J)
            IN=4
            GO TO 28
22          ICL=4
23          F(1)=G(I,J)
            F(3)=A(I+1,J+1)*(G(I+1,J+1)-G(I,J+1))+G(I,J+1)
            S(3)=X(I)+A(I+1,J+1)
            T(1)=Y(J+1)-A(I,J)
            IN=3
            GO TO 28
24          F(1)=G(I,J+1)
            F(2)=G(I+1,J+1)
            F(3)=G(I+1,J)
            S(1)=X(I+1)-A(I,J+1)
            S(2)=X(I+1)
            T(1)=Y(J+1)
            T(3)=Y(J+1)-A(I+1,J)
```

```
                IN=3
                ICL=1
                GO TO 28
25              ICL=2
26              IF (BND(I,J).GE.1.AND.BND(I+1,J+1).GE.1) GOTO 22
                F(2)=G(I,J+1)
                F(3)=G(I+1,J)
                S(3)=X(I)+A(I+1,J)
                T(2)=Y(J)+A(I,J+1)
                T(3)=Y(J)
                IN=3
                GOTO 28
27              F(1)=G(I,J)
                F(2)=G(I+1,J+1)
                F(3)=G(I+1,J)
                S(1)=X(I+1)-A(I,J)
                S(2)=X(I+1)
                T(2)=Y(J)+A(I+1,J+1)
                T(3)=Y(J)
                IN=3
                ICL=1
28              DO 42 L=1,NCL1
                LL=0
                ISW=1
                I1=1
                I2=2
29              G1=F(I1)
                G2=F(I2)
                IF (B(L)-G1) 30,37,31
30              IF (B(L)-G2) 34,37,32
31              IF (G2-B(L)) 34,37,32
32              LL=LL+1
                IF (ABS(S(I2)-S(I1)) .LT. 0.0001) GOTO 33
                SLOPE=(T(I2)-T(I1))/(S(I2)-S(I1))
                IF (ABS(SLOPE).GT.1.0) GOTO 33
                XX(LL)=(S(I2)-S(I1))*(B(L)-G1)/(G2-G1)+S(I1)
                YY(LL)=(XX(LL)-S(I1))*SLOPE+T(I1)
                GOTO 34
33              SLOPE=(S(I2)-S(I1))/(T(I2)-T(I1))
                YY(LL)=(T(I2)-T(I1))*(B(L)-G1)/(G2-G1)+T(I1)
                XX(LL)=(YY(LL)-T(I1))*SLOPE+S(I1)
34              I1=I1+1
                I2=I2+1
                GOTO (35,36),ISW
35              IF (I2.LE.IN) GOTO 29
                I1=1
                I2=IN
                ISW=2
                GOTO 29
36              IF (LL.EQ.0) GOTO 42
                IF (LL.EQ.2) GOTO 39
37              IF(ISEE.EQ.1)TYPE 38,LL,B(L),I,J,(F(I1),I1=1,4)
38              FORMAT (' WARNING...',I2,F10.5,2I2,4F10.5)
                GOTO 42
39              IF (XX(1).LT.XX(2)) GOTO 40
                TEM=XX(1)
                XX(1)=XX(2)
```

```
            XX(2)=TEM
            TEM=YY(1)
            YY(1)=YY(2)
            YY(2)=TEM
40          LS=LS+1
            XS(LS)=XX(1)
            YS(LS)=YY(1)
            LS=LS+1
            XS(LS)=XX(2)
            YS(LS)=YY(2)
            IF (LS.LT. 8000) GOTO 42
            TYPE 41
41          FORMAT (' DIMENSION ON XS IS TOO SMALL IN SUB CONTOR')
            CALL EXIT
42          CONTINUE
            GOTO (43,24,43,27),ICL
43          CONTINUE
            GOTO 2
44          CONTINUE
            LSSAV=LS
            IONE=1
            ISW=-1
            EPS=.001
45          L=1
            IPS=1
            JJ=0
            IONE=1
            JJ=JJ+1
            XP(JJ)=XS(L)
            YP(JJ)=YS(L)
46          JJ=JJ+1
            IF (JJ.LT.300) GOTO 48
            TYPE 47
47          FORMAT (' DIMENSION ON XP,YP HAS BEEN EXCEEDED')
            CALL EXIT
48          XP(JJ)=XS(L+1)
            YP(JJ)=YS(L+1)
            K=0
49          K=K+1
            IF (K.EQ.L+1) GOTO 55
             IF (ABS(XS(K)-XS(L+1)).GT.EPS.OR.ABS(YS(K)-YS(L+1))
     *      .GT.EPS) GOTO 55
50          LS=LS-2
            IF (LS.LE.0) GOTO 56
            L1=L
            L=K-2
            K1=K
            IF ((-1.)**K.LT.0.0) GOTO 51
            TEM=XS(K-1)
            XS(K-1)=XS(K)
            XS(K)=TEM
            TEM=YS(K-1)
            YS(K-1)=YS(K)
            YS(K)=TEM
            L=K-3
            K1=K-1
51          IF (K.GT.L1+1) GOTO 52
```

```
         L=K1
52       IF (L.GT.0) GOTO 53
         L=1
53       DO 54 LL=L1,LS
         XS(LL)=XS(LL+2)
54       YS(LL)=YS(LL+2)
         GOTO (46,56),IPS
55       IF (K.LT.LS.AND.X(K).LT.FLOAT(M)) GOTO 49
         IPS=2
         L1=L
         LS=LS-2
         GOTO 53
56       J1=(JJ-1)*(1+ISW)/2+1
         CALL LNPLT(XP,YP,JJ)
         IX=1023/2*(1+(YP(J1)-WCX)/WS)
         IF(IONE.GT.1)GO TO 60
         IY=1023/2*(1+(XP(J1)-WCY+XL)/WS)
         GO TO 61
60       IY=1023/2*(1+(XL-XP(J1)-WCY)/WS)
61       CONTINUE
         CALL MOVCLP(IX,IY)
         DO 59 J=2,JJ
         IF (ISW.LT.0) GOTO 57
         J1=JJ+1-J
         GOTO 58
57       J1=J
58       IX=1023/2*(1+(YP(J1)-WCX)/WS)
         IF(IONE.GT.1)GO TO 62
         IY=1023/2*(1+(XP(J1)-WCY+XL)/WS)
         GO TO 63
62       IY=1023/2*(1+(XL-XP(J1)-WCY)/WS)
63       CONTINUE
         CALL VECLP(IX,IY)
59       CONTINUE
         IF(IONE.GT.1)GO TO 64
         IONE=IONE+1
         GO TO 56
64       CONTINUE
         IF(LS.LE.0)RETURN
         ISW=-ISW
         GOTO 45
         END
         SUBROUTINE PLOT(X,Y,N)
         COMMON/FIXT/DX,DY
         IF(N.LT.0)GO TO 1
         A=100.*(X+DX)
         B=100.*(Y+DY)
         NA=IFIX(A)
         NB=IFIX(B)
         IF(N.EQ.3)CALL MOVETO(NA,NB)
         IF(N.EQ.2)CALL VECTO(NA,NB)
         RETURN
1        DX=DX+X
         DY=DY+Y
         RETURN
         END
         SUBROUTINE FINI
```

```
      CALL APND
      RETURN
      END
      SUBROUTINE IDPLOT(XX,YY)
      COMMON/FIXT/DX,DY
      DX=2.0
      DY=4.0
      CALL SETDIS1
      WS=8.0
      WCX=0.0
      WCY=0.0
      RETURN
      END
      SUBROUTINE SYMBL4(XX,YY,HT,NOO,NNN,I)
      RETURN
      END
      SUBROUTINE NUMBER(XXX,YYY,HHH,RRR,ZZZ,IIIK)
      RETURN
      END
```

```fortran
C          THIS SET OF SUBROUTINES PERFORMS CLIPPING ON
C          DATA PASSED TO IT THROUGH VECLP AND MOVCLP
C          CALLS. (4-20-72)
           SUBROUTINE VECLP(IX,IY)
           COMMON/CLP/IN,IXP,IYP,MN
           LOGICAL IN
           IF(.NOT.IN) GO TO 12
C          THE PREVIOUS POINT WAS INSIDE OF THE FIELD
C          OF VISION DEFINED BY THE SCOPE.
           N=0
           IF(IX.GT.1023)N=N+1
           IF(IX.LT.0)N=N+2
           IF(IY.GT.1023)N=N+3
           IF(IY.LT.0)N=N+6
           N=N+1
           S=(IY-IYP)/(IX-IXP)
           GO TO(1,3,5,4,2,4,6,8,6),N
C
C          ENTIRE LINE IS VISIBLE
C
1          CALL VECTO(IX,IY)
           GO TO 11
C
C          LINE GOES OUT TOP RIGHT HAND SIDE OF SCREEN
C
2          IXS=(1023-IYP)/S+IXP
           IF(IXS.GT.1023) GO TO 3
           CALL VECTO(IXS,1023)
           GO TO 10
3          IF(IY.EQ.IYP)GO TO 35
           IYS=(1023-IXP)*S+IYP
           CALL VECTO(1023,IYS)
           GO TO 10
35         CALL VECTO(1023,IY)
           GO TO 10
C
C          LINE GOES OUT TOP OR TOP LEFT HAND SIDE
C          OF SCREEN.
C
4          IF(IX.EQ.IXP)GO TO 45
           IXS=(1023-IYP)/S+IXP
           IF(IXS.LT.0)GO TO 5
           CALL VECTO(IXS,1023)
           GO TO 10
45         CALL VECTO(IX,1023)
           GO TO 10
C
C          LINE GOES OUT LEFT HAND SIDE OF SCREEN.
C
5          IF(IY.EQ.IYP)GO TO 55
           IYS=IYP-S*IXP
           CALL VECTO(0,IYS)
           GO TO 10
55         CALL VECTO(0,IY)
           GO TO 10
C
C          LINE GOES OUT OF BOTTOM OR BOTTOM LEFT CORNER.
```

```
C
6          IF(IX.EQ.IXP)GO TU 65
           IXS=IXP-IYP/S
           IF(IXS.LT.0)GO TO 7
           CALL VECTO(IXS,0)
           GO TU 10
65         CALL VECTO(IX,0)
           GO TO 10
7          IYS=IYP-IXP*S
           CALL VECTO(0,IYS)
           GO TU 10
C
C          LINE GOES OUT BOTTOM RIGHT HAND CORNER.
C
8          IYS=IYP+S*(1023-IXP)
           IF(IYS.LT.0)GO TO 9
           CALL VECTO(1023,IYS)
           GO TO 10
9          IXS=IXP-IYP/S
           CALL VECTO(IXS,0)
10         IN=.FALSE.
11         IXP=IX
           IYP=IY
           MN=N-1
           RETURN
C
C          LINE IS COMING INTO FIELD OF VISION.
C
12         N=0
           S=(IY-IYP)/(IX-IXP)
           IF(IX.GT.1023)N=N+1
           IF(IX.LT.0)N=N+2
           IF(IY.GT.1023)N=N+3
           IF(IY.LT.0)N=N+6
           N=N+1
           GO TO (13,23,23,23,23,23,23,23,23),N
13         GO TO (15,17,16,14,16,18,20,18),MN
14         IXS=(1023-IY)/S+IX
           IF(IXS.GT.1023)GO TO 15
           CALL MOVETO(IXS,1023)
           CALL VECTO(IX,IY)
           GO TO 22
C
C          LINE IS COMING FROM RIGHT SIDE OF SCREEN.
C
15         IF(IY.EQ.IYP)GO TO 155
           IYS=(1023-IX)*S+IY
           CALL MOVETO(1023,IYS)
           CALL VECTO(IX,IY)
           GO TO 22
155        CALL MOVETO(1023,IY)
           CALL VECTO(IX,IY)
           GO TU 22
C
C          LINE IS COMING FROM TOP OR TOP LEFT.
C
16         IF(IX.EQ.IXP)GO TO 166
```

```
          IXS=(1023-IY)/S+IX
          IF(IXS.LT.0)GO TO 17
          CALL MOVETO(IXS,1023)
          CALL VECTO(IX,IY)
          GO TO 22
166       CALL MOVETO(IX,1023)
          CALL VECTO(IX,IY)
          GO TO 22
C
C         LINE IS COMING FROM LEFT SIDE OF SCREEN.
C
17        IF(IY.EQ.IYP)GO TO 175
          IYS=IY-S*IX
          CALL MOVETO(0,IYS)
          CALL VECTO(IX,IY)
          GO TO 22
175       CALL MOVETO(0,IY)
          CALL VECTO(IX,IY)
          GO TO 22
18        IF(IX.EQ.IXP)GO TO 185
          IXS=IX-IY/S
          IF(IXS.LT.0)GO TO 19
          CALL MOVETO(IXS,0)
          CALL VECTO(IX,IY)
          GO TO 22
185       CALL MOVETO(IX,0)
          CALL VECTO(IX,IY)
          GO TO 22
19        IYS=IY-IX*S
          CALL MOVETO(0,IYS)
          CALL VECTO(IX,IY)
          GO TO 22
20        S=(IY-IYP)/(IX-IXP)
          IYS=IY+S*(1023-IX)
          IF(IYS.LT.0) GO TO 21
          CALL MOVETO(1023,IYS)
          CALL VECTO(IX,IY)
          GO TO 22
21        IXS=IX-IY/S
          CALL MOVETO(IXS,0)
          CALL VECTO(IX,IY)
22        IN=.TRUE.
23        MN=N-1
          IXP=IX
          IYP=IY
          RETURN
          END
          SUBROUTINE MOVCLP(IX,IY)
          COMMON/CLP/IN,IXP,IYP,MN
          LOGICAL IN
          IN=.TRUE.
          N=0
          IF(IX.GT.1023)N=N+1
          IF(IX.LT.0)N=N+2
          IF(IY.GT.1023)N=N+3
          IF(IY.LT.0)N=N+6
          N=N+1
```

```
        GO TO (1,2,2,2,2,2,2,2,2),N
1       CALL MOVETO(IX,IY)
        GO TO 3
2       IN=.FALSE.
3       IXP=IX
        IYP=IY
        MN=N-1
        RETURN
        END
        SUBROUTINE DOTCLP(IX,IY)
        COMMON/CLP/IN,IXP,IYP,MN
        LOGICAL IN
        N=0
        IF(IX.GT.1023)N=N+1
        IF(IX.LT.0)N=N+2
        IF(IY.GT.1023)N=N+3
        IF(IY.LT.0)N=N+6
        N=N+1
        GO TO (1,2,2,2,2,2,2,2,2),N
1       CALL DOTAT(IX,IY)
2       MN=N-1
        IXP=IX
        IYP=IY
        RETURN
        END
```

APPENDIX VI

MISCELLANEOUS PROGRAMS

Routine Name	Function
SAVCOR	Saves a core image of currently executing program
PSEUD	Sets up pseudo-interrupts
SLEEP	Dismisses process for specified number of ms.
GETIT	Determines latest version of saved core and gets it.
PRINT	Reads in data file and formats for line printer listing.
TYPE	Reads in data file and formats for teletype listing.
APFLE	Appends error function to a display file.

```
TITLE    SAVCOR
         ENTRY ABSAV
         EXTERNAL FLAG1
SAVREG:  BLOCK 20
ABSAV:   0
         MOVEM    17,SAVREG+17
         MOVEI    17,SAVREG
         BLT      17,SAVREG+16
         MOVEI    1,400000
         GEVEC
         MOVEM    2,SAVLOCH
         HRLZI    1,1B18+1B35
         MOVE     3,FLAG1
         XORI     3,1
         MOVEM    3,FLAG1
         HRRO     2,RSTART(3)
         GTJFN
         HALTF
         HRRZM    1,JFNSAVH
         MOVEI    1,400000
         HRLI     2,1
         HRRI     2,RENTRY
         SEVEC
         HRLI     1,400000
         HRR      1,JFNSAV
         MOVE     2,[777760,,20]
         SAVE
RENTRY:  MOVE     1,400000
         HRLI     2,1
         HRR      2,SAVLOC
         SEVEC
         HRLZI    17,SAVREG
         BLT      17,17
         JRA      16,(16)
RSTART:  [ASCIZ/P.DMP;1/]
         [ASCIZ/P.DMP;2/]
         END
```

```
;           THIS PROGRAM ENABLES PSEUDO-INTERRUPTS TO
;           BE GENERATED. WHEN ∆V IS TYPE IN, THE
;           INTERRUPT CHANGES THE SENSE OF THE
;           TTY FLAG.
            TITLE INTRPT
            ENTRY PSEUD
            EXTERNAL FLGS
            TTY=FLGS
SAVR        BLOCK 20
CHNTAB:     BLOCK 44
LEVTAB:     BLOCK 3
PCSAV:      BLOCK 3
PSEUD:      0
            MOVEM    17,SAVR+17
            MOVEI    17,SAVR
            BLT      17,SAVR+16
            HRLI     1,1
            MOVEM    1,CHNTAB
            HRRI     1,PCSAV
            MOVEM    1,LEVTAB
            MOVEI    1,400000
            HRLI     2,LEVTAB
            HRRI     2,CHNTAB
            SIR
            MOVEI    1,400000
            EIR
            MOVEI    1,400000
            MOVE     2,[400000,,0]
            AIC
            MOVE     2,[26,,0]
            ATI
            HRLZI    17,SAVR
            BLT      17,17
            JRA      16,(16)
MES:        ASCIZ\TTY FLAG CHANGED....\
LOC:        SETCMM   0,TTY
            MOVEM    1,SAVR
            HRROI    1,MES
            PSOUT
            MOVE     1,SAVR
            DEBRK
            END
```

```
        TITLE  SLEEP
;       DISMISSES THE PROCESS FOR SPECIFIED NUMBER OF MS.
        ENTRY  SLEEP
SLEEP:  0
        MOVEM   1,SA1H
        MOVEI   1,10000
        DISMS
        MOVE    1,SA1
        JRA     16,(16)
        END
```

SEARCH STENEX

```
        TITLE START RIGHT FIB JOB
        LOC 200000
        ;THIS PROGRAM DETERMINES THE APPROPRIATE P.DMP FILE
        ;TO RUN FROM A FIB REQUEST......
FNAM1:  ASCIZ/REQUESTED-F-I-B.INPUT/
FNAM2:  ASCIZ/P.DMP/
GETIT:  MOVE    1,[XWD 100001,-2]
        HRROI   2,FNAM1
        GTJFN
        HALTF
        MOVE    2,[XWD 1,7]
        MOVEI   3,2
        GTFDB
        HLRZ    2,2
        ROT     2,-1
        JUMPL   2,ODD
        MOVE    1,[XWD 100001,2]
        JRST    NXT
ODD:    MOVE    1,[XWD 100001,1]
NXT:    HRROI   2,FNAM2
        GTJFN
        HALTF
        HRLI    1,400000
        GET
        HRRZ    1,120
        JRST    0(1)
        HALTF
        END GETIT
```

```
        DIMENSION UU(18,82),VV(18,82),PP(18,82)
        DIMENSION A(18,82),U(2500),V(2500),P(2500)
        DIMENSION MESS(7)
        EQUIVALENCE (U,UU),(V,VV),(P,PP)
        TYPE 100
100     FORMAT(1H ,'INPUT FILE:',$)
        ACCEPT 101,NAME
101     FORMAT(A5)
        NAME=NAME+32
        CALL IFILE(22,NAME)
        READ(22,1)(MESS(I),I=1,7)
1       FORMAT(7A5)
        NAME=NAME+6
        CALL IFILE(23,NAME)
        READ(23)M
        READ(23)U,V,P
        READ(23)DT,RHOA,TIME,NCYCLE,MU,EPS1
        READ(23)KUMN,KUMX,LDMN,LDMX,DR,DZ,KMAX,LMAX
        WRITE(24,16)(MESS(I),I=1,7)
16      FORMAT(1H ,7A5)
        WRITE(24,17)NCYCLE
17      FORMAT(1H ,'CYCLE ',I)
        DO 20 L=1,LMAX
        WRITE(24,18)L
18      FORMAT(1H ,'L=',I3)
        WRITE(24,19)
19      FORMAT(1H ,'K         V              U             P')
        DO 20 K=1,KMAX
20      WRITE(24,21)K,UU(K,L),VV(K,L),PP(K,L)
21      FORMAT(1H ,I3,3X,3F)
        STOP
        END
```

```
          INTEGER BLN(2),BNDRY
          DIMENSION UU(18,82),VV(18,82),PP(18,82)
          DIMENSION ME(18,82)
          DIMENSION BNDRY(18,82)
          DIMENSION VZ(18,82),SI(18,82)
          DIMENSION DIMR(150),DIMZ(150)
          DIMENSION A(18,82),U(2500),V(2500),P(2500)
          DIMENSION MESS(7)
          DIMENSION BPX(100),BPY(100)
          DIMENSION XB(100),YB(100),NSEQ(100)
          DIMENSION XBP(50,2),YBP(50,2)
          DIMENSION M(2500)
          EQUIVALENCE(U,UU),(V,VV),(P,PP)
          EQUIVALENCE(M,ME)
          COMMON/CLP/IN,IXP,IYP,MN
          COMMON/STUFF/DR,DZ,KMAX,LMAX
          COMMON/WINDOW/WS,WCX,WCY,XL
          COMMON/CONLVL/NCLS,NCL
          INTEGER EMP,BND,FULL,OB
          DATA EMP,BND,FULL,OB/16,32,8,2048/
          TYPE 100
100       FORMAT(1H ,'INPUT FILE:',$)
          ACCEPT 101,NAME
          NAME=NAME+32
          CALL IFILE(22,NAME)
101       FORMAT(A5)
          READ(22,1)(MESS(I),I=1,7)
1         FORMAT(7A5)
          READ(22,2)KMAX,LMAX
2         FORMAT(2I)
          READ(22,3)SMIN,EPS1
3         FORMAT(2F)
          READ(22,4)D,D,MU,RHOA
4         FORMAT(4F)
          READ(22,5)DR
5         FORMAT(F)
          READ(22,5)DZ
          READ(22,6)D
6         FORMAT(I)
          READ(22,3)BPX(1),BPY(1)
          MM=2
7         READ(22,3)BPX(MM),BPY(MM)
          IF(BPX(1).EQ.BPX(MM).AND.BPY(1).EQ.BPY(MM))GO TO 8
          MM=MM+1
          GO TO 7
8         MM=MM-1
          DO 9 I=1,6
9         READ(22,6)D
          N=1
10        READ(22,11)XB(N),YB(N),NSEQ(N)
11        FORMAT(2F,I)
          IF(NSEQ(N).EQ.1)GO TO 12
          N=N+1
          GO TO 10
12        KMAXZZ=KMAX-2
          LMAXZZ=LMAX-2
          KMAXZ=KMAX-1
```

```
          LMAXZ=LMAX-1
          XBMAX=DR*KMAXZZ
          YBMAX=DZ*LMAXZZ
          N=0
          MM=0
13        N=N+1
          MM=MM+1
          XBP(MM,1)=YB(N)
          YBP(MM,1)=XB(N)
          IF(NSEQ(N).EQ.0)GO TO 13
          XBP(MM,1)=YB(N)
          YBP(MM,1)=XB(N)
          MM=MM+1
          XBP(MM,1)=YBMAX
          YBP(MM,1)=XBMAX
          BLN(1)=MM
          MM=0
14        MM=MM+1
          N=N+1
          XBP(MM,2)=YB(N)
          YBP(MM,2)=XB(N)
          IF(NSEQ(N).EQ.1)GO TO 15
          GO TO 14
15        XBP(MM,2)=YB(N)
          YBP(MM,2)=XB(N)
          BLN(2)=MM
          NAME=NAME+6
          CALL IFILE(23,NAME)
          READ(23)M
          READ(23)U,V,P
          READ(23)DT,RHOA,TIME,NCYCLE,MU,EPS1
          READ(23)KDMN,KDMX,LDMN,LDMX,DR,DZ,KMAX,LMAX
202       TYPE 16
16        FORMAT(1H ,'LOOK AT:',$)
          ACCEPT 17,IVAR
17        FORMAT(A1)
          IF(IVAR.EQ.' ')CALL EXIT
          TYPE 18
18        FORMAT(1H ,'START AT L=',$)
          ACCEPT 19,L1
19        FORMAT(I)
          TYPE 20
20        FORMAT(1H ,'LIST TO L=',$)
          ACCEPT 19,L2
          ACCEPT 203,NDUM
203       FORMAT(I)
          TYPE 201,NCYCLE
201       FORMAT(1H ,'CYCLE ',I3)
          IF(IVAR.EQ.'P')GO TO 24
          IF(IVAR.EQ.'V')GO TO 27
          DO 22 L=L1,L2
          TYPE 21,L
21        FORMAT(1H ,'L=',I3)
          DO 22 K=1,18
22        TYPE 23,K,UU(K,L)
23        FORMAT(1H ,'K=',I3,' U(K,L)=',F12.7)
          GO TO 202
```

```
24          DO 25 L=L1,L2
            TYPE 21,L
            DO 25 K=1,18
25          TYPE 26,K,PP(K,L)
26          FORMAT(1H ,'K=',I3,' P(K,L)=',F15.7)
            GO TO 202
27          DO 28 L=L1,L2
            TYPE 21,L
            DO 28 K=1,18
28          TYPE 29,K,VV(K,L)
29          FORMAT(1H ,'K=',I3,' V(K,L)=',F12.7)
            GO TO 202
            END
```

```
;       READ FROM FILE FOR01.DAT AND APPEND TO FILE
;       ERRORS.DAT. DELETE FOR01.DAT WHEN DONE.....
SEARCH STENEX
TITLE APPEND TO FILE
ENTRY   APFLE
LITERAL         APFLE
SAVR:   BLOCK 22
FNAM1:  ASCIZ/FOR01.DAT/
FNAM2:  ASCIZ/ERROR.DAT;1/
APFLE:  0
        MOVEM   17,SAVR+17
        MOVEI   17,SAVR
        BLT     17,SAVR+16
        HRROI   2,FNAM1
        MOVSI   1,(1B2!1B17)
        STJFN
        HALTF
        MOVEM   1,JFN1#
        MOVE    2,[44B5!1B19]
        OPENF
        HALTF
        HRROI   2,FNAM2
        MOVSI   1,(1B3!1B17)
        STJFN
        HALTF
        MOVEM   1,JFN2#
        MOVE    2,[44B5!1B22]
        OPENF
        HALTF
LOOP:   MOVE    1,JFN1
        BIN
        MOVE    3,2
        GTSTS
        TLNE    2,1000
        JRST    DONE
        MOVE    2,3
        MOVE    1,JFN2
        BOUT
        JRST    LOOP
DONE:   MOVE    1,JFN1
        CLF
        HALTF
        HRLZI   17,SAVR
        BLT     17,17
        JRA     16,(16)
        END
```

APPENDIX VII

LISTING OF INPUT DATA FOR
BALL VALVE

```
STARR-EDWARDS BALL VALVE(EXTENDED)
18,92,1,0
.01,.2,0.,0.
0.,0.,.0032,1.06
.2
.2
2,2,17,2.91
0.,0.
1.7,0.
1.7,8.8
1.58,9.31
1.56,9.56
1.58,9.82
1.62,10.07
1.736,10.53
1.736,10.78
1.683,11.04
1.524,11.42
0.69,11.48
0.846,11.74
0.90,11.99
1.397,12.10
1.46,12.35
1.65,12.73
2.984,14.13
3.175,14.51
3.2,14.89
3.2,18.
0.,18.
0.,11.255
.198,11.255
.388,11.171
.561,11.072
.700,10.938
.827,10.777
.908,10.595
.949,10.399
.949,10.209
.908,10.105
.827,9.823
.700,9.662
.561,9.528
.388,9.429
.198,9.367
0.,9.345
0.,0.
0
1,18,1,92,0.,-10.,0,0
2,10,1,1,0.,-10.,0,1
2,17,92,92,0.,-7.57,1,0
0
38,.05,22.45,.1
1.7,-.0001
1.7,8.8
1.58,9.31
1.56,9.56
1.58,9.82
```

```
1.62,10.07
1.736,10.53
1.736,10.76
1.683,11.04
1.524,11.42
0.89,11.46
0.846,11.74
0.9,11.99
1.397,12.19
1.46,12.35
1.65,12.73
2.984,14.13
3.175,14.51
3.202,14.59,2
-.0001,11.255
0.196,11.253
0.386,11.171
0.561,11.072
0.700,10.938
0.827,10.777
0.908,10.595
0.949,10.399
0.949,10.209
0.908,10.105
0.827,9.823
0.700,9.662
0.561,9.528
0.388,9.429
0.196,9.367
-0.0001,9.345,1
1,0,,3.2,0,,18,,.2885,.9
1,18,1,92
.0005
20
.1
.0001
.45
N
.01
20
20
4
```

APPENDIX VIII

LISTING OF DATA FOR
BALL VALVE SOLUTION

STARR-EDWARDS BALL VALVE(EXTENDED)
CYCLE   277
L= 1

K	U	V	P
1	0.0000000	-35.2557037	0.0000000
2	-0.0075029	-35.2557037	0.0000000
3	-0.0131090	-35.3133917	0.0000000
4	-0.0182086	-35.3263162	0.0000000
5	-0.0226600	-35.3329953	0.0000000
6	-0.0265614	-35.3382938	0.0000000
7	-0.0304269	-35.3437446	0.0000000
8	-0.0342607	-35.3448391	0.0000000
9	-0.0341043	-34.7626600	0.0000000
10	0.0341043	0.0682824	0.0000000
11	0.0000000	0.0000000	0.0000000
12	0.0000000	0.0000000	0.0000000
13	0.0000000	0.0000000	0.0000000
14	0.0000000	0.0000000	0.0000000
15	0.0000000	0.0000000	0.0000000
16	0.0000000	0.0000000	0.0000000
17	0.0000000	0.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 2

K	U	V	P
1	0.0000000	-35.2409236	-25.9982292
2	-0.0075029	-35.2409236	-25.9982292
3	-0.0131090	-35.3010952	-26.1790384
4	-0.0182086	-35.3151243	-26.5270531
5	-0.0226600	-35.3228718	-27.0173922
6	-0.0265614	-35.3290867	-27.6058041
7	-0.0304269	-35.3348572	-28.2245919
8	-0.0342607	-35.3361804	-28.7877768
9	-0.0341043	-34.7583905	-29.2185578
10	0.0341043	0.0000000	-29.4657301
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 3

K	U	V	P
1	0.0000000	-35.2413002	-58.8076420
2	-0.0000038	-35.2413002	-58.8076420
3	0.0015547	-35.3034645	-58.9373298
4	0.0030556	-35.3178225	-59.1852829
5	0.0043301	-35.3254676	-59.5273599
6	0.0050547	-35.3311151	-59.9238522
7	0.0046078	-35.3355452	-60.3163153
8	0.0010023	-35.3332594	-60.6190503
9	0.0001551	-34.7578723	-60.6135242
10	-0.0001551	0.0000000	-60.6192805
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000

K	U	V	P
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 4

K	U	V	P
1	0.0000000	-35.2408037	-91.6542172
2	-0.0005199	-35.2408037	-91.6542172
3	0.0005913	-35.3050075	-91.7389899
4	0.0018273	-35.3199217	-91.9006832
5	0.0030747	-35.3277832	-92.1191096
6	0.0041225	-35.3333227	-92.3628353
7	0.0048516	-35.3374459	-92.5882347
8	0.0066662	-35.3363112	-92.7424811
9	0.0002392	-34.7522557	-92.8500302
10	-0.0002392	0.0000000	-92.8584397
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 5

K	U	V	P
1	0.0000000	-35.2393445	-124.3235874
2	-0.0010812	-35.2393445	-124.3235874
3	-0.0004366	-35.3056680	-124.3757321
4	0.0005936	-35.3214685	-124.4758968
5	0.0019466	-35.3299677	-124.6103379
6	0.0034631	-35.3359006	-124.7581425
7	0.0050768	-35.3402894	-124.8953906
8	0.0063552	-35.3389189	-125.0059348
9	0.0003226	-34.7471148	-125.0681379
10	-0.0003226	0.0000000	-125.0796080
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 6

K	U	V	P
1	0.0000000	-35.2367852	-156.8759889
2	-0.0017108	-35.2367852	-156.8759889
3	-0.0015540	-35.3053719	-156.9040962
4	-0.0007146	-35.3224441	-156.9606797
5	0.0007568	-35.3320152	-157.0384786
6	0.0025955	-35.3386700	-157.1260919
7	0.0044356	-35.3433210	-157.2108832
8	0.0060378	-35.3418738	-157.2789331
9	0.0004056	-34.7424567	-157.3213567
10	-0.0004056	0.0000000	-157.3354588

K	U	V	P
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 7

K	U	V	P
1	0.0000000	-35.2331959	-189.3525612
2	-0.0023061	-35.2331959	-189.3525612
3	-0.0026064	-35.3041831	-189.3615429
4	-0.0019422	-35.3228927	-189.3844683
5	-0.0003663	-35.3339322	-189.4205161
6	0.0017443	-35.3415921	-189.4663316
7	0.0039077	-35.3466470	-189.5146244
8	0.0057533	-35.3451062	-189.5568450
9	0.0004883	-34.7382482	-189.5867535
10	-0.0004883	0.0000000	-189.6029790
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 8

K	U	V	P
1	0.0000000	-35.2292165	-221.7791439
2	-0.0025798	-35.2292165	-221.7791439
3	-0.0031120	-35.3026159	-221.7707601
4	-0.0025603	-35.3231080	-221.7639112
5	-0.0009363	-35.3358284	-221.7651927
6	0.0013630	-35.3446953	-221.7787509
7	0.0037333	-35.3502281	-221.8022016
8	0.0056511	-35.3484869	-221.8287797
9	0.0005705	-34.7343184	-221.8519454
10	-0.0005705	0.0000000	-221.8695157
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 9

K	U	V	P
1	0.0000000	-35.2266345	-254.1678143
2	-0.0019593	-35.2266345	-254.1678143
3	-0.0021293	-35.3020564	-254.1429256
4	-0.0015640	-35.3238367	-254.1079488
5	-0.0001432	-35.3378758	-254.0776287
6	0.0019433	-35.3478353	-254.0643033
7	0.0041479	-35.3538290	-254.0705991

K	U	V	P
8	0.0058341	-35.3517771	-254.0892553
9	0.0006522	-34.7303998	-254.1100872
10	-0.0006522	0.0000000	-254.1283411
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 10

K	U	V	P
1	0.0000000	-35.2290750	-286.5192001
2	0.0004745	-35.2290750	-286.5192001
3	0.0018432	-35.3052828	-286.4793879
4	0.0026255	-35.3265159	-286.4189599
5	0.0032137	-35.3402659	-286.3604803
6	0.0041310	-35.3505190	-286.3246132
7	0.0053742	-35.3568736	-286.3191259
8	0.0063303	-35.3545625	-266.3363367
9	0.0007330	-34.7261980	-286.3594410
10	-0.0007330	0.0000000	-286.3775831
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 11

K	U	V	P
1	0.0000000	-35.2426425	-318.8180928
2	0.0059613	-35.2426425	-318.8180928
3	0.0108315	-35.3169449	-318.7699024
4	0.0121493	-35.3335336	-318.6936048
5	0.0107562	-35.3432108	-318.6156344
6	0.0087228	-35.3516936	-318.5625193
7	0.0075305	-35.3581905	-318.5498644
8	0.0070213	-35.3561960	-318.5713035
9	0.0008126	-34.7215280	-318.6013107
10	-0.0008126	0.0000000	-318.6186370
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 12

K	U	V	P
1	0.0000000	-35.2760255	-351.0333714
2	0.0157937	-35.2760255	-351.0333714
3	0.0270152	-35.3437353	-350.9921883
4	0.0293990	-35.3484020	-350.9229612

K	U	V	P
5	0.0243600	-35.3470109	-350.8455013
6	0.0165756	-35.3495941	-350.7860047
7	0.0105188	-35.3557192	-350.7694159
8	0.0075182	-35.3556961	-350.7981715
9	0.0008908	-34.7165678	-350.8393545
10	-0.0008908	0.0000000	-350.8550045
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 13

K	U	V	P
1	0.0000000	-35.3393737	-383.1229997
2	0.0307032	-35.3393737	-383.1229997
3	0.0517871	-35.3937209	-383.1160930
4	0.0561562	-35.3756569	-383.0950414
5	0.0456579	-35.3523087	-383.0551249
6	0.0284295	-35.3418253	-383.0081974
7	0.0139093	-35.3462588	-382.9893213
8	0.0070234	-35.3516214	-383.0227335
9	0.0009674	-34.7122382	-383.0740531
10	-0.0009674	0.0000000	-383.0874567
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 14

K	U	V	P
1	0.0000000	-35.4410753	-415.0495161
2	0.0498085	-35.4410753	-415.0495161
3	0.0841169	-35.4741767	-415.1130323
4	0.0920375	-35.4201984	-415.1976858
5	0.0750737	-35.3605587	-415.2515461
6	0.0445843	-35.3259444	-415.2488638
7	0.0168991	-35.3254613	-415.2280693
8	0.0043263	-35.3419695	-415.2510804
9	0.0010419	-34.7105924	-415.2986449
10	-0.0010419	0.0000000	-415.3092359
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 15

K	U	V	P
1	0.0000000	-35.5820086	-446.8123731

K	U	V	P
2	0.0693563	-35.5820086	-446.8123731
3	0.1184604	-35.5874881	-446.9801788
4	0.1322621	-35.4856245	-447.2300340
5	0.1102661	-35.3746358	-447.4452887
6	0.0643802	-35.3008628	-447.5333807
7	0.0184666	-35.2884606	-447.5109917
8	-0.0018255	-35.3243276	-447.4878614
9	0.0011141	-34.7148474	-447.4913222
10	-0.0011142	0.0000000	-447.4988435
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 16

K	U	V	P
1	0.0000000	-35.7481584	-478.4891163
2	0.0818991	-35.7481584	-478.4891163
3	0.1430397	-35.7253037	-478.7695822
4	0.1653096	-35.5711285	-479.2150561
5	0.1440054	-35.3990287	-479.6478678
6	0.0853848	-35.2692086	-479.8861001
7	0.0179313	-35.2318600	-479.8701335
8	-0.0115784	-35.2967545	-479.7309269
9	0.0011837	-34.7283579	-479.6130364
10	-0.0011837	0.0000000	-479.6172832
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 17

K	U	V	P
1	0.0000000	-35.9045625	-510.2625419
2	0.0769643	-35.9045625	-510.2625419
3	0.1400217	-35.8624723	-510.6146117
4	0.1716546	-35.6667407	-511.2139736
5	0.1617890	-35.4383834	-511.8680452
6	0.1020792	-35.2403719	-512.3191704
7	0.0163551	-35.1584375	-512.3422821
8	-0.0218047	-35.2596991	-511.9657297
9	0.0012499	-34.7515583	-511.6049205
10	-0.0012499	0.0000000	-511.6059561
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

```
L= 18
K             U              V              P
 1      0.0000000    -35.9950975    -542.4087797
 2      0.0439717    -35.9950975    -542.4087797
 3      0.0892037    -35.9539613    -542.7357484
 4      0.1254494    -35.7476365    -543.3447440
 5      0.1400227    -35.4925394    -544.1168700
 6      0.1036897    -35.2327429    -544.8094983
 7      0.0194716    -35.0870207    -544.9520130
 8     -0.0229936    -35.2185551    -544.1555534
 9      0.0013123    -34.7760033    -543.4001316
10     -0.0013123      0.0000000    -543.3986862
11      0.0000000    -10.0000000       0.0000000
12      0.0000000    -10.0000000       0.0000000
13      0.0000000    -10.0000000       0.0000000
14      0.0000000    -10.0000000       0.0000000
15      0.0000000    -10.0000000       0.0000000
16      0.0000000    -10.0000000       0.0000000
17      0.0000000    -10.0000000       0.0000000
18      0.0000000    -10.0000000       0.0000000
L= 19
K             U              V              P
 1      0.0000000    -35.9514102    -575.2259125
 2     -0.0231934    -35.9514102    -575.2259125
 3     -0.0245368    -35.9386485    -575.4125793
 4      0.0009593    -35.7702058    -575.8002777
 5      0.0467369    -35.5468553    -576.4356558
 6      0.0708051    -35.2715619    -577.2743081
 7      0.0425161    -35.0707028    -577.6639660
 8      0.0041674    -35.1854555    -576.2270172
 9      0.0013701    -34.7752225    -574.9551733
10     -0.0013701      0.0000000    -574.9524985
11      0.0000000    -10.0000000       0.0000000
12      0.0000000    -10.0000000       0.0000000
13      0.0000000    -10.0000000       0.0000000
14      0.0000000    -10.0000000       0.0000000
15      0.0000000    -10.0000000       0.0000000
16      0.0000000    -10.0000000       0.0000000
17      0.0000000    -10.0000000       0.0000000
18      0.0000000    -10.0000000       0.0000000
L= 20
K             U              V              P
 1      0.0000000    -35.7093308    -608.9381878
 2     -0.1224383    -35.7093308    -608.9381878
 3     -0.2025060    -35.7522771    -608.9038257
 4     -0.2160406    -35.6748153    -608.8500698
 5     -0.1515240    -35.5606493    -608.9779590
 6     -0.0281433    -35.3767302    -609.5923562
 7      0.1159470    -35.2245048    -610.2796797
 8      0.0898108    -35.1768613    -608.0556218
 9      0.0014228    -34.6946239    -606.3213353
10     -0.0014228      0.0000000    -606.3169469
11      0.0000000    -10.0000000       0.0000000
12      0.0000000    -10.0000000       0.0000000
13      0.0000000    -10.0000000       0.0000000
14      0.0000000    -10.0000000       0.0000000
15      0.0000000    -10.0000000       0.0000000
```

K	U	V	P
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 21

K	U	V	P
1	0.0000000	-35.2265522	-643.6794479
2	-0.2428349	-35.2265522	-643.6794479
3	-0.4274152	-35.3463557	-643.4273724
4	-0.5158106	-35.3996880	-642.8332706
5	-0.4720987	-35.4650758	-642.0731176
6	-0.2339700	-35.5382036	-641.7500381
7	0.2865500	-35.7516021	-642.3495193
8	0.2682112	-35.2029610	-639.5371188
9	0.0014710	-34.4476208	-637.7373715
10	-0.0014710	0.0000000	-637.7203320
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 22

K	U	V	P
1	0.0000000	-34.4952852	-679.5053636
2	-0.3671225	-34.4952852	-679.5053636
3	-0.6655240	-34.7058758	-679.1723673
4	-0.8572167	-34.9054176	-678.2025699
5	-0.8900878	-35.1844881	-676.4011388
6	-0.5712988	-35.6964756	-674.1460492
7	0.6005464	-36.9279411	-673.3530317
8	0.5585609	-35.2519568	-670.8787014
9	0.0015149	-33.9297220	-669.7760527
10	-0.0015149	0.0000000	-669.7063152
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 23

K	U	V	P
1	0.0000000	-33.5426595	-716.3895969
2	-0.4778434	-33.5426595	-716.3895969
3	-0.8767802	-33.8575944	-716.2130330
4	-1.1703163	-34.2044853	-715.3574754
5	-1.3113833	-34.6908428	-713.0187978
6	-0.9876788	-35.7666381	-708.3091666
7	1.0523841	-38.9757711	-703.7328859
8	0.9385956	-35.2910344	-703.2048483
9	0.0015558	-33.0590799	-703.5322343
10	-0.0015558	0.0000000	-703.3305843
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000

K	U	V	P
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 24

K	U	V	P
1	0.0000000	-32.4163906	-754.2335917
2	-0.5647062	-32.4163906	-754.2335917
3	-1.0324574	-32.8597095	-754.4009988
4	-1.3807374	-33.3756447	-754.2470549
5	-1.5740538	-34.0774149	-752.7400632
6	-1.2785430	-35.7471529	-747.2712626
7	1.5185734	-41.7966390	-736.6449837
8	1.3138046	-35.3060547	-739.0522887
9	0.0015950	-31.8364639	-740.5057628
10	-0.0015950	0.0000000	-740.0949527
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 25

K	U	V	P
1	0.0000000	-31.1632540	-792.9777135
2	-0.6281805	-31.1632540	-792.9777135
3	-1.1317574	-31.7718003	-793.4378986
4	-1.4612365	-32.5296983	-794.0670703
5	-1.5387375	-33.5733995	-794.5629363
6	-1.1015646	-35.8929683	-792.8811689
7	1.7755537	-44.7370127	-777.4902587
8	1.5620841	-35.3512883	-781.0705011
9	0.0016342	-30.3822685	-781.6339438
10	-0.0016342	0.0000000	-781.0338442
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 26

K	U	V	P
1	0.0000000	-29.8191313	-832.7893470
2	-0.6737169	-29.8191313	-832.7893470
3	-1.1969293	-30.6274146	-833.2990263
4	-1.4699228	-31.7255236	-833.9636777
5	-1.2800676	-33.3725072	-835.2092807
6	-0.2122785	-36.7970038	-838.8087605
7	1.6861749	-46.7714906	-828.4534295
8	1.6064524	-35.5268575	-828.3775453
9	0.0016747	-28.8866356	-825.9410341

10	-0.0016747	0.0000000	-825.2897491
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 27

K	U	V	P
1	0.0000000	-28.4227613	-873.9951108
2	-0.6998858	-28.4227613	-873.9951108
3	-1.2361363	-29.4482660	-874.5191996
4	-1.4795000	-30.9412826	-874.6690606
5	-1.0983221	-33.3875921	-873.7977971
6	1.1044203	-39.0025448	-874.6188958
7	1.4006086	-47.2974978	-882.0260991
8	1.5081670	-35.8602356	-875.7069562
9	0.0017178	-27.4828948	-870.9813212
10	-0.0017178	0.0000000	-870.4006378
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 28

K	U	V	P
1	0.0000000	-27.0307504	-916.5451978
2	-0.6977563	-27.0307504	-916.5451978
3	-1.2204068	-28.2887425	-917.4204548
4	-1.4378544	-30.1945001	-917.8811987
5	-1.0275985	-33.4478721	-915.5198936
6	1.9169836	-42.0481306	-909.5184211
7	1.2468875	-46.9171774	-925.3187631
8	1.3992354	-36.2182587	-920.1577757
9	0.0017646	-26.1809323	-915.4815753
10	-0.0017646	0.0000000	-914.9829601
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 29

K	U	V	P
1	0.0000000	-25.6971717	-959.7103451
2	-0.6685963	-25.6971717	-959.7103451
3	-1.1325859	-27.2269551	-961.1601089
4	-1.2441632	-29.6099652	-963.0578239
5	-0.7824071	-33.6224221	-963.0086650
6	1.7579073	-44.6990877	-953.7183051

7	1.2351853	-46.6687743	-964.5730336
8	1.3334380	-36.5162920	-964.2826398
9	0.0018163	-24.9405013	-959.7451691
10	-0.0018163	0.0000000	-959.2961301
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 30

K	U	V	P
1	0.0000000	-24.4336925	-1002.6408315
2	-0.6336090	-24.4336925	-1002.6408315
3	-1.0189235	-26.2934852	-1004.3390517
4	-0.9480336	-29.2899411	-1007.2085403
5	-0.2140049	-34.1928314	-1010.7652706
6	0.9989842	-46.0016292	-1006.8379019
7	1.1474224	-47.0146373	-1006.8550755
8	1.3108338	-36.8710700	-1009.3036715
9	0.0018741	-23.7213038	-1003.9001287
10	-0.0018741	0.0000000	-1003.4738344
11	0.0000000	-19.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-19.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 31

K	U	V	P
1	0.0000000	-23.2039552	-1045.2207227
2	-0.6168104	-23.2039552	-1045.2207227
3	-0.9522980	-25.4377551	-1046.7000727
4	-0.7476373	-29.1571893	-1049.0059902
5	0.3953287	-35.2879468	-1051.8103514
6	0.2838942	-45.9680870	-1059.2034322
7	0.8724453	-47.7106962	-1052.3784489
8	1.3487501	-37.5205923	-1054.6502147
9	0.0019397	-22.4668719	-1048.0564975
10	-0.0019397	0.0000000	-1047.6196699
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 32

K	U	V	P
1	0.0000000	-21.9601812	-1087.9624498
2	-0.6239120	-21.9601812	-1087.9624498
3	-0.9473307	-24.5935045	-1089.2295421

4	-0.6929861	-29.0861577	-1090.9900398
5	0.5456726	-36.5081489	-1092.8204518
6	-0.0649632	-45.4133928	-1102.9154391
7	0.4604113	-48.2745085	-1100.3299852
8	1.4751910	-38.6867214	-1100.0723534
9	0.0020147	-21.0946059	-1093.4634928
10	-0.0020147	0.0000000	-1092.9610164
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 33

K	U	V	P
1	0.0000000	-20.6628442	-1131.3066774
2	-0.6507896	-20.6628442	-1131.3066774
3	-0.9865006	-23.7150868	-1132.5740491
4	-0.7300576	-29.0021066	-1134.4149292
5	0.1784079	-37.3405188	-1137.1066750
6	-0.2307453	-45.0010747	-1144.8925131
7	0.0704051	-48.5636894	-1150.1829468
8	1.6720768	-40.4250029	-1147.0397238
9	0.0021016	-19.5387861	-1143.3270623
10	-0.0021016	0.0000000	-1142.7005057
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 34

K	U	V	P
1	0.0000000	-19.2816239	-1175.4457515
2	-0.6928425	-19.2816239	-1175.4457515
3	-1.0599559	-22.7669269	-1176.9867365
4	-0.8595240	-28.8216107	-1179.4761990
5	-0.4116542	-37.6096487	-1183.7304246
6	-0.4938803	-44.8210262	-1191.9400890
7	-0.1077552	-48.8978658	-1201.2344461
8	1.8136792	-42.4803708	-1199.4885050
9	0.0022030	-17.8510444	-1201.5936386
10	-0.0022030	0.0000000	-1200.8759428
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 35

K	U	V	P

1	0.0000000	-17.7929228	-1220.2209842
2	-0.7467107	-17.7929228	-1220.2209842
3	-1.1619476	-21.7188766	-1222.3403484
4	-1.0806561	-28.4575228	-1226.2305666
5	-1.0359859	-37.3549659	-1233.3510399
6	-0.8707759	-44.7773270	-1242.9710806
7	-0.0295833	-49.6601120	-1253.7553955
8	1.7072297	-44.3490993	-1260.5380502
9	0.0023214	-16.2629366	-1268.0795279
10	-0.0023214	0.0000000	-1267.4910810
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 36

K	U	V	P
1	0.0000000	-16.1709398	-1265.1441109
2	-0.8134976	-16.1709398	-1265.1441109
3	-1.2986379	-20.5333099	-1268.0530970
4	-1.3913201	-27.8301869	-1273.8465194
5	-1.5874746	-36.7364835	-1284.2539747
6	-1.2172970	-44.8390037	-1296.8277980
7	0.1142202	-50.8944385	-1309.7818059
8	1.3214640	-45.6698254	-1325.8278791
9	0.0024596	-15.0352031	-1335.6289317
10	-0.0024596	0.0000000	-1335.3836585
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 37

K	U	V	P
1	0.0000000	-14.3826196	-1309.6050781
2	-0.8968298	-14.3826196	-1309.6050781
3	-1.4814356	-19.1598065	-1313.4324041
4	-1.7785331	-26.8846549	-1321.4357619
5	-2.0173961	-35.9587729	-1335.0755398
6	-1.4314029	-45.0451475	-1351.8084821
7	0.1511175	-52.3638651	-1368.4610513
8	0.9112755	-46.5149581	-1389.4221981
9	0.0026190	-14.1906867	-1398.6589064
10	-0.0026190	0.0000000	-1398.6970719
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000

| 18 | 0.0000000 | -10.0000000 | 0.0000000 |

L= 38

K	U	V	P
1	0.0000000	-12.3849273	-1353.1096515
2	-1.0016974	-12.3849273	-1353.1096515
3	-1.7180967	-17.5409313	-1357.8537155
4	-2.2012109	-25.6214842	-1368.0795070
5	-2.3440472	-35.1702794	-1384.9536565
6	-1.5254509	-45.4373851	-1406.3140240
7	0.0778529	-53.8390972	-1428.1783861
8	0.7445161	-47.2483639	-1451.1453596
9	0.0028005	-13.5022359	-1461.9771254
10	-0.0028005	0.0000000	-1462.1205118
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 39

K	U	V	P
1	0.0000000	-10.1221569	-1395.6821014
2	-1.1344352	-10.1221569	-1395.6821014
3	-2.0115207	-15.6196052	-1401.1555214
4	-2.6264815	-24.0829956	-1413.2172105
5	-2.6235399	-34.4271455	-1433.2521011
6	-1.6023830	-45.9928367	-1459.3802069
7	-0.1038604	-55.1862888	-1488.7393874
8	0.6535582	-48.0518036	-1515.7446687
9	0.0030033	-12.8991486	-1531.7628954
10	-0.0030033	0.0000000	-1531.9501658
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 40

K	U	V	P
1	0.0000000	-7.5282578	-1438.3790132
2	-1.3002142	-7.5282578	-1438.3790132
3	-2.3605570	-13.3437280	-1444.2135815
4	-3.0644949	-22.2984098	-1457.3631298
5	-2.9405016	-33.6974893	-1480.0064501
6	-1.8254875	-46.5824150	-1510.9451164
7	-0.5033405	-56.3007817	-1549.8224322
8	0.1696290	-48.7031136	-1583.7805208
9	0.0032254	-12.7482397	-1597.7448274
10	-0.0032254	0.0000000	-1598.0379891
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000

K	U	V	P
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 41

K	U	V	P
1	0.0000000	-4.5380912	-1483.7713216
2	-1.4985760	-4.5380912	-1483.7713216
3	-2.7617680	-10.6654746	-1489.5055306
4	-3.5599902	-20.2405058	-1502.7575989
5	-3.4003539	-32.8672964	-1526.9875575
6	-2.3562798	-46.9912753	-1562.0033678
7	-1.2002769	-57.1378112	-1607.9730403
8	-0.6333273	-49.1333187	-1644.3161157
9	0.0034641	-13.3473020	-1645.1571372
10	-0.0034641	0.0000000	-1645.3744148
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 42

K	U	V	P
1	0.0000000	-1.1112795	-1536.1473945
2	-1.7171370	-1.1112795	-1536.1473945
3	-3.2068017	-7.5398953	-1541.4337118
4	-4.1614103	-17.8172465	-1553.8428028
5	-4.0779796	-31.7784905	-1578.2781739
6	-3.2082786	-47.0561128	-1614.7478905
7	-2.0669913	-57.8041837	-1659.7823475
8	-1.0296894	-49.9370191	-1686.4323292
9	0.0037159	-14.3168746	-1688.5407504
10	-0.0037159	0.0000000	-1688.5842618
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 43

K	U	V	P
1	0.0000000	2.7090766	-1600.8223270
2	-1.9141533	2.7090766	-1600.8223270
3	-3.6727005	-3.9248161	-1606.1013241
4	-4.8882360	-14.8948472	-1617.6608068
5	-4.9512300	-30.3150017	-1640.1314784
6	-4.1877640	-46.8091767	-1673.1461187
7	-2.7792889	-58.5842617	-1710.3041012
8	-1.3067802	-51.1001326	-1729.7872019
9	0.0039775	-15.5456552	-1731.1181922
10	-0.0039775	0.0000000	-1730.9879561
11	0.0000000	-10.0000000	0.0000000

K	U	V	P
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 44

K	U	V	P
1	0.0000000	6.4780799	-1679.5670290
2	-1.8887191	6.4780799	-1679.5670290
3	-4.1319691	0.3192238	-1690.4580642
4	-5.6841335	-11.3851216	-1704.3888245
5	-5.8823688	-28.4698833	-1720.3617704
6	-5.0891345	-46.3887230	-1743.6368067
7	-3.3509181	-59.5604934	-1768.6794933
8	-1.5857876	-52.4907507	-1777.0159294
9	0.0042447	-17.0354402	-1772.6088923
10	-0.0042447	0.0000000	-1772.2585660
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 45

K	U	V	P
1	0.0000000	14.6186573	-1804.0536579
2	-4.0747339	14.6186573	-1804.0536579
3	-4.7249329	3.8962002	-1802.3449604
4	-6.3056460	-7.6042862	-1827.0998870
5	-6.6548575	-26.2749799	-1825.3202040
6	-5.7921015	-45.8741847	-1831.8166819
7	-3.7414213	-60.7501090	-1840.5311045
8	-1.6915402	-54.1282587	-1828.9568324
9	0.0045110	-18.6245121	-1813.5686454
10	-0.0045110	0.0000000	-1813.0897035
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 46

K	U	V	P
1	0.0000000	14.9199745	-1925.3411752
2	-0.1552941	14.9199745	-1925.3411752
3	-8.5136396	15.1374444	-1996.7666876
4	-5.9754948	-7.2509249	-1997.8735831
5	-6.9940013	-23.4098312	-1951.2503271
6	-6.1945283	-45.2143043	-1937.7044451
7	-3.7856869	-62.2576088	-1932.6258127
8	-1.4567509	-56.0597859	-1898.1218387

9	0.0059688	-19.9962653	-1852.5101852
10	-0.0036950	0.0000000	-1852.8769959
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 47

K	U	V	P
1	0.0000000	2.4666596	-1886.8537296
2	6.2219077	2.4666596	-1886.8537296
3	10.8261753	4.8435224	-2029.6445165
4	-3.1583171	5.1933441	-2101.9010854
5	-6.6262764	-18.5505470	-2076.4189635
6	-6.2950439	-44.1162154	-2052.2238363
7	-3.4207452	-64.2549530	-2057.8970250
8	-0.4249512	-58.7659344	-2026.3216694
9	-0.0544809	-20.3420555	-1783.1510354
10	0.0000000	-10.0000000	0.0000000
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 48

K	U	V	P
1	0.0000000	-0.6890116	-1815.1779708
2	1.5726660	-0.6890116	-1815.1779708
3	4.3704715	0.0422457	-1962.4202375
4	0.7637725	7.7713452	-2180.5690464
5	-5.4736280	-11.6470918	-2196.4564596
6	-6.4636752	-41.8065302	-2157.4890849
7	-3.0613174	-66.7980894	-2230.1036168
8	3.0563267	-64.8898542	-2337.9675348
9	-0.1720533	-17.3166517	-2493.0419636
10	0.0000000	-10.0000000	0.0000000
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 49

K	U	V	P
1	0.0000000	-10.0000000	0.0000000
2	0.0000000	-10.0000000	0.0000000
3	-7.9295501	-10.0000000	0.0000000
4	7.7525625	-7.8859668	-2202.6059826
5	-3.1094193	-1.4554800	-2233.2870078

K	U	V	P
6	-7.6249190	-36.1053802	-2229.6427984
7	-4.6389894	-68.6761588	-2420.2963759
8	0.5314005	-69.7513148	-2746.6394801
9	-0.1014509	-16.7239975	-3003.3855189
10	0.0000000	-10.0000000	0.0000000
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 50

K	U	V	P
1	0.0000000	-10.0000000	0.0000000
2	0.0000000	-10.0000000	0.0000000
3	0.0000000	-10.0000000	0.0000000
4	0.8679453	-10.0000000	0.0000000
5	-1.3785837	0.8527263	-2340.5131374
6	-10.6947289	-25.4495509	-2329.2128046
7	-9.1591323	-68.4187494	-2536.8452494
8	-3.7352296	-74.1907001	-3034.1101859
9	0.6393637	-20.9045600	-3282.7533085
10	0.0000000	-10.0000000	0.0000000
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 51

K	U	V	P
1	0.0000000	-10.0000000	0.0000000
2	0.0000000	-10.0000000	0.0000000
3	0.0000000	-10.0000000	0.0000000
4	0.0000000	-10.0000000	0.0000000
5	3.8932115	-10.0000000	0.0000000
6	-14.0690284	-6.3685837	-2658.6879839
7	-15.9220656	-63.8478756	-2505.6760062
8	-7.7183429	-80.5835098	-3166.4481808
9	0.2538849	-28.3921167	-5356.4116408
10	0.0000000	-10.0000000	0.0000000
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 52

K	U	V	P
1	0.0000000	-10.0000000	0.0000000
2	0.0000000	-10.0000000	0.0000000

3	0.0000000	-10.0000000	0.0000000
4	0.0000000	-10.0000000	0.0000000
5	11.0363042	-10.0000000	0.0000000
6	-8.7338346	13.1279802	-2241.8237899
7	-24.8936653	-44.6384065	-2241.7419267
8	-34.4863281	-66.4308406	-1671.3421096
9	-4.6010386	-55.6848310	1349.2407699
10	0.0000000	17.2093526	0.0000000
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 53

K	U	V	P
1	0.0000000	-10.0000000	0.0000000
2	0.0000000	-10.0000000	0.0000000
3	0.0000000	-10.0000000	0.0000000
4	0.0000000	-10.0000000	0.0000000
5	-1.8468273	-10.0000000	0.0000000
6	0.6648684	10.7269044	-1939.8427431
7	-9.8963916	-33.2441505	-1934.1238823
8	-9.0742799	-65.8013768	-880.2858298
9	-6.9660420	-56.7313954	-41.0856515
10	10.8955994	-0.8981968	35.3639945
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 54

K	U	V	P
1	0.0000000	-10.0000000	0.0000000
2	0.0000000	-10.0000000	0.0000000
3	0.0000000	-10.0000000	0.0000000
4	0.0000000	-10.0000000	0.0000000
5	-6.2145130	-10.0000000	0.0000000
6	3.5503850	1.2398723	-1987.8413763
7	10.7053762	-41.7020530	-1805.8980119
8	3.7512957	-59.9670313	-675.4626115
9	-3.9708870	-49.0022462	454.0255521
10	2.6689086	-7.4749160	659.0322559
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 55

K	U	V	P
1	0.0000000	-10.0000000	0.0000000
2	0.0000000	-10.0000000	0.0000000
3	0.0000000	-10.0000000	0.0000000
4	0.0000000	-10.0000000	0.0000000
5	-5.7409237	91.2245519	0.0000000
6	14.2916791	-19.7608359	-5826.4608730
7	31.5379404	-63.1230831	-2226.7240894
8	22.9458012	-55.5735648	-11.3308048
9	2.2918534	-30.0384369	924.9372785
10	-1.1208065	-4.1346366	1077.7477969
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 56

K	U	V	P
1	0.0000000	-10.0000000	0.0000000
2	0.0000000	-10.0000000	0.0000000
3	0.0000000	-10.0000000	0.0000000
4	-91.7462833	66.7213745	0.0000000
5	57.7631138	-53.4464046	1611.7630203
6	87.6653433	-65.8341736	581.6073869
7	67.3591949	-56.9175430	-521.4857389
8	37.6721635	-33.9734089	239.1475593
9	2.2583450	2.7057737	758.0634360
10	-1.7911037	-9.1252179	1135.0159210
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 57

K	U	V	P
1	0.0000000	3.1215359	0.0000000
2	0.0000000	3.1215359	0.0000000
3	-66.2976310	-0.2734088	0.0000000
4	67.8119279	-67.7059501	4521.3531752
5	82.1846686	-89.2536588	1773.7367053
6	71.6161616	-72.3617412	76.5063718
7	47.4819653	-43.6177567	-680.0063182
8	-2.2319803	12.2523122	-276.3591897
9	-0.7900204	1.4577353	314.1016443
10	0.2892652	-1.1882713	330.8744174
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000

K	U	V	P
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 58

K	U	V	P
1	0.0000000	-11.1752063	12336.2062993
2	7.1425916	-11.1752063	12336.2062993
3	26.8606447	-31.3382827	12053.7736016
4	58.0243528	-115.8561748	2086.8569289
5	61.6281807	-109.9570305	490.4133496
6	38.1078307	-59.9298611	-918.8340534
7	-12.0279596	4.1399569	-1359.9464905
8	-0.8863377	2.0927758	-1467.5873753
9	1.4104599	-0.8844587	365.1631777
10	0.0000000	-10.0000000	0.0000000
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 59

K	U	V	P
1	0.0000000	-67.6995300	10762.8804194
2	28.2579828	-67.6995300	10762.8804194
3	66.4000869	-101.0398702	8295.9867318
4	50.3437944	-123.1539608	2537.5178878
5	38.5263070	-110.8407839	-1033.8737492
6	-10.4148436	-14.1181769	-1987.2607340
7	3.9388387	-9.6310310	-1753.9994654
8	0.0000000	-10.0000000	0.0000000
9	0.0000000	-10.0000000	0.0000000
10	0.0000000	-10.0000000	0.0000000
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 60

K	U	V	P
1	0.0000000	-103.7774128	7875.0812311
2	18.0357771	-103.7774128	7875.0812311
3	17.9017810	-112.8894924	5633.4267606
4	14.9814844	-126.8144441	2524.0254824
5	13.4218359	-113.3428006	-1689.3799279
6	-28.3087343	29.2625580	-3215.0677268
7	0.0000000	-10.0000000	0.0000000
8	0.0000000	-10.0000000	0.0000000
9	0.0000000	-10.0000000	0.0000000
10	0.0000000	-10.0000000	0.0000000
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000

14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 61

K	U	V	P
1	0.0000000	-100.9282577	6299.4255920
2	-1.4269879	-100.9282577	6299.4255920
3	-6.9572740	-104.5676307	5401.5514304
4	-18.3950447	-110.3089037	3313.5332961
5	-24.4982339	-101.1141646	-268.0738796
6	23.5034473	-18.6341695	-3317.7078937
7	0.0000000	4.4151714	0.0000000
8	0.0000000	-10.0000000	0.0000000
9	0.0000000	-10.0000000	0.0000000
10	0.0000000	-10.0000000	0.0000000
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 62

K	U	V	P
1	0.0000000	-82.0268176	7249.2925127
2	-9.4524147	-82.0268176	7249.2925127
3	-24.2235413	-78.5732798	6937.6349498
4	-48.7850070	-71.1473010	6551.7301161
5	-71.0051447	-61.7820285	6843.1646426
6	-30.8816820	-47.4380437	9759.1740687
7	-2.1127798	-21.3554438	11156.9516855
8	-2.3212576	-9.4508944	11039.9224358
9	0.0000000	-10.0000000	0.0000000
10	0.0000000	-10.0000000	0.0000000
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 63

K	U	V	P
1	0.0000000	-61.0513538	8974.6271123
2	-10.4888464	-61.0513538	8974.6271123
3	-19.9424645	-58.9772038	9091.1351193
4	-26.6532000	-55.1183693	9374.7530927
5	-30.7295561	-49.5087102	9748.5064019
6	-28.8223471	-42.7287024	10250.0698092
7	-11.8039612	-34.6807394	10845.1576466
8	3.0989040	-23.6842545	10922.1556718
9	-8.4641266	1.9203038	10813.3572648
10	0.0000000	-10.0000000	0.0000000

11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 64

K	U	V	P
1	0.0000000	-48.0237648	10140.2689266
2	-6.5144645	-49.0237648	10140.2689266
3	-12.3783922	-46.8163989	10192.4043643
4	-17.0440353	-44.5687357	10306.2742884
5	-19.6211230	-41.6940223	10471.1466032
6	-19.4451826	-38.5640446	10651.4581042
7	-15.5734409	-35.3689339	10785.2859917
8	-7.5060854	-29.9761403	10758.5877674
9	3.6140152	-8.9402761	10557.2669330
10	0.0000000	-10.0000000	0.0000000
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 65

K	U	V	P
1	0.0000000	-39.2339587	10699.1912733
2	-4.3952355	-39.2339587	10699.1912733
3	-8.4488472	-38.4817481	10720.8591449
4	-11.8650601	-37.0899104	10767.6330517
5	-14.5764716	-35.2052815	10827.6770013
6	-16.7118967	-32.9520442	10889.1692507
7	-18.5021603	-30.3771906	10942.5710077
8	-18.3719682	-27.2695485	11003.0272539
9	-3.7242250	-22.1141746	11203.4913647
10	0.0000000	-1.7042921	0.0000000
11	0.0000000	-10.0000000	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 66

K	U	V	P
1	0.0000000	-32.7809941	11003.3453936
2	-3.2265659	-32.7809941	11003.3453936
3	-6.2917649	-32.2437845	11012.9590641
4	-9.0870317	-31.2188104	11034.5007415
5	-11.5596260	-29.7830068	11064.5493987
6	-13.7298098	-27.9716820	11100.0852222
7	-15.6395679	-25.7971689	11139.6524618

8	-17.1441833	-23.2427102	11185.6238479
9	-16.7556953	-20.2422004	11253.2191473
10	-0.9474240	-16.4704140	11385.5554285
11	0.0000000	-0.5778699	0.0000000
12	0.0000000	-10.0000000	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 67

K	U	V	P
1	0.0000000	-27.7731452	11186.8556152
2	-2.5038268	-27.7731452	11186.8556152
3	-4.9176803	-27.3558840	11192.3685792
4	-7.1682177	-26.5508436	11205.3072574
5	-9.2020882	-25.4102226	11224.4010466
6	-10.9661058	-23.9664044	11248.8709884
7	-12.3875807	-22.2522296	11278.1510251
8	-13.3515997	-20.2983048	11311.6719323
9	-13.6755399	-18.1159643	11348.4818051
10	-12.9286770	-15.6517979	11387.9755634
11	-0.1632654	-12.6533406	11459.0904238
12	0.0000000	0.1379119	0.0000000
13	0.0000000	-10.0000000	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 68

K	U	V	P
1	0.0000000	-23.8043524	11304.1952747
2	-1.9841709	-23.8043524	11304.1952747
3	-3.9018744	-23.4757982	11307.9379807
4	-5.6968657	-22.8357306	11316.6216324
5	-7.3193691	-21.9278596	11329.5559334
6	-8.7238844	-20.7788803	11346.1807864
7	-9.8679575	-19.4175338	11365.8829155
8	-10.7055454	-17.8776562	11387.9882293
9	-11.1680695	-16.1946934	11411.7673161
10	-11.1207076	-14.3875325	11436.4244538
11	-10.2417969	-12.4073720	11461.1223834
12	0.3643513	-9.9969536	11502.2087033
13	0.0000000	0.5214294	0.0000000
14	0.0000000	-10.0000000	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 69

K	U	V	P
1	0.0000000	-20.6370538	11380.9534843
2	-1.5833387	-20.6370538	11380.9534843
3	-3.1149578	-20.3776099	11383.6028176
4	-4.5505652	-19.8665647	11389.6015594

K	U	V	P
5	-5.8591222	-19.1397460	11398.4860974
6	-6.9850114	-18.2191715	11409.8714228
7	-7.9100730	-17.1280686	11423.3159023
8	-8.6305102	-15.8926735	11438.3040490
9	-9.0994525	-14.5432414	11454.2718540
10	-9.2925952	-13.1119853	11470.6656459
11	-9.1132488	-11.6174702	11487.0134304
12	-8.2658842	-10.0162219	11502.9529231
13	0.7333984	-8.0561981	11528.4317667
14	0.0000000	0.8250144	0.0000000
15	0.0000000	-10.0000000	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 70

K	U	V	P
1	0.0000000	-18.0966489	11431.6749881
2	-1.2698404	-18.0966489	11431.6749881
3	-2.4995453	-17.8909115	11433.5947233
4	-3.6544986	-17.4803033	11437.8273931
5	-4.7052887	-16.8942090	11444.0639066
6	-5.6258691	-16.1501907	11452.0404051
7	-6.3941801	-15.2665272	11461.4561694
8	-6.9932403	-14.2633086	11471.9659584
9	-7.4132065	-13.1623397	11483.1833663
10	-7.6514237	-11.9871075	11494.7089488
11	-7.6979968	-10.7625307	11506.1969991
12	-7.4833322	-9.5074728	11517.4483071
13	-6.7199975	-8.2015147	11528.4687402
14	0.9929661	-6.6570982	11544.5655334
15	0.0000000	1.0449895	0.0000000
16	0.0000000	-10.0000000	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 71

K	U	V	P
1	0.0000000	-16.0498023	11465.4234173
2	-1.0230351	-16.0498023	11465.4234173
3	-2.0149123	-15.8858262	11466.8521593
4	-2.9483720	-15.5536693	11469.9174213
5	-3.8004800	-15.0774768	11474.4127291
6	-4.5511453	-14.4710701	11480.1603864
7	-5.1835570	-13.7486484	11486.9593206
8	-5.6847005	-12.9256522	11494.5833134
9	-6.0459046	-12.0186059	11502.7834224
10	-6.2641085	-11.0443003	11511.2948726
11	-6.3439776	-10.0186003	11519.8451589
12	-6.2930600	-8.9561586	11528.1943726
13	-6.0865238	-7.8693524	11536.2145501
14	-5.5252249	-6.7534882	11544.0133522
15	1.1783590	-5.4968363	11555.5570955
16	0.0000000	1.5398376	0.0000000
17	0.0000000	-10.0000000	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 72

K	U	V	P
1	0.0000000	-14.3947914	11487.9666391

K	U	V	P
2	-0.8271110	-14.3947914	11487.9666391
3	-1.6298886	-14.2634893	11489.0603843
4	-2.3866137	-13.9931291	11491.3423109
5	-3.0740958	-13.6036849	11494.6745830
6	-3.6913754	-13.1060306	11498.9378984
7	-4.2100213	-12.5112165	11503.9989846
8	-4.6245217	-11.8311004	11509.7081783
9	-4.9276774	-11.0781722	11515.9030567
10	-5.1157004	-10.2650326	11522.4157023
11	-5.1882357	-9.4033047	11529.0752175
12	-5.1502294	-8.5014187	11535.7105183
13	-5.0145886	-7.5626191	11542.1624417
14	-4.7868238	-6.5887843	11548.3396250
15	-4.3494494	-5.5954350	11554.3175052
16	1.8793025	-4.6030451	11561.7124858
17	0.0000000	2.6211165	0.0000000
18	0.0000000	-10.0000000	0.0000000

L= 73

K	U	V	P
1	0.0000000	-13.0536282	11503.0158805
2	-0.6701973	-13.0536282	11503.0158805
3	-1.3212323	-12.9481023	11503.8748393
4	-1.9355136	-12.7270039	11505.6182752
5	-2.4983293	-12.4069893	11508.1537078
6	-2.9966639	-11.9966818	11511.4011365
7	-3.4103960	-11.5047559	11515.2712474
8	-3.7575274	-10.9404567	11519.6655999
9	-4.0044019	-10.3134021	11524.4779299
10	-4.1558959	-9.6330971	11529.5994590
11	-4.2102541	-8.9082081	11534.9239233
12	-4.1667993	-8.1455617	11540.3528820
13	-4.0256317	-7.3472012	11545.7878011
14	-3.8015499	-6.4993972	11551.1046285
15	-3.5360725	-5.5431495	11556.1740036
16	-3.6101837	-4.3246374	11561.1115033
17	1.6944709	-2.6211153	11570.2894079
18	0.0000000	-10.0000000	11570.2894079

L= 74

K	U	V	P
1	0.0000000	-11.9658354	11512.9904384
2	-0.5435331	-11.9658354	11512.9904384
3	-1.0718353	-11.8808354	11513.6790584
4	-1.5764015	-11.6995279	11515.0408382
5	-2.0271026	-11.4359188	11517.0130069
6	-2.4310685	-11.0969378	11519.5408958
7	-2.7727987	-10.6895314	11522.5643414
8	-3.0442734	-10.2211089	11526.0170336
9	-3.2390058	-9.6993890	11529.8287506
10	-3.3519788	-9.1320316	11533.9287120
11	-3.3794990	-8.5260227	11538.2493037
12	-3.3190366	-7.8866784	11542.7340875
13	-3.1672877	-7.2165781	11547.3576384
14	-2.9066201	-6.5167602	11552.1720174
15	-2.4556042	-5.7952241	11557.3410439
16	-1.5516379	-5.0900898	11562.9057894
17	0.3896617	-4.5245430	11568.5305121
18	0.0000000	3.9367294	11568.5305121

L= 75

K	U	V	P
1	0.0000000	-11.0838190	11519.4903250
2	-0.4406739	-11.0838190	11519.4903250
3	-0.8691338	-11.0153080	11520.0513537
4	-1.2732157	-10.8665556	11521.1331780
5	-1.6427492	-10.6494196	11522.6927708
6	-1.9684775	-10.3695763	11524.6920409
7	-2.2421045	-10.0327500	11527.0886133
8	-2.4563009	-9.6451327	11529.8364806
9	-2.6046133	-9.2133270	11532.8866551
10	-2.6811487	-8.7442234	11536.1892181
11	-2.6797261	-8.2449576	11539.6972309
12	-2.5916835	-7.7233733	11543.3696220
13	-2.4011193	-7.1897446	11547.1694181
14	-2.0780237	-6.6603784	11551.0375733
15	-1.5753820	-6.1622488	11554.8084984
16	-0.8494713	-5.7320824	11558.0343204
17	0.0000000	-5.3463104	11559.8470467
18	0.0000000	5.3463104	11559.8470467

L= 76

K	U	V	P
1	0.0000000	-10.3695257	11523.5903795
2	-0.3568480	-10.3695257	11523.5903795
3	-0.7038382	-10.3143420	11524.0525949
4	-1.0306127	-10.1925172	11524.9225433
5	-1.3285378	-10.0141196	11526.1696773
6	-1.5896364	-9.7838964	11527.7664299
7	-1.8065930	-9.5067158	11529.6818810
8	-1.9726913	-9.1880002	11531.8805474
9	-2.0816266	-8.8337934	11534.3248966
10	-2.1270861	-8.4508902	11536.9731123
11	-2.1019699	-8.0471987	11539.7800254
12	-1.9973142	-7.6325386	11542.6913398
13	-1.8016391	-7.2199691	11545.6318977
14	-1.5022744	-6.8273138	11548.4852838
15	-1.0905037	-6.4777223	11551.0618808
16	-0.5732014	-6.1917502	11553.0752140
17	0.0000000	-5.9007564	11554.1812527
18	0.0000000	5.9007564	11554.1812527

L= 77

K	U	V	P
1	0.0000000	-9.7920549	11526.0237391
2	-0.2884752	-9.7920549	11526.0237391
3	-0.5689713	-9.7476728	11526.4073509
4	-0.8325591	-9.6483000	11527.1122689
5	-1.0718598	-9.5024545	11528.1161415
6	-1.2799846	-9.3141634	11529.3980139
7	-1.4505148	-9.0876770	11530.9328335
8	-1.5774403	-8.8278821	11532.6921950
9	-1.6550238	-8.5404482	11534.6427570
10	-1.6775858	-8.2320355	11536.7454040
11	-1.6393173	-7.9106435	11538.9529179
12	-1.5343729	-7.5861118	11541.2044833
13	-1.3576743	-7.2706901	11543.4202860
14	-1.1067663	-6.9794127	11545.4928512
15	-0.7846621	-6.7295453	11547.2822013

16	-0.4029492	-6.5322851	11548.6185561
17	0.0000000	-6.2904820	11549.3181656
18	0.0000000	6.2904820	11549.3181656

L= 78

K	U	V	P
1	0.0000000	-9.3259967	11527.2979746
2	-0.2328103	-9.3259967	11527.2979746
3	-0.4591686	-9.2903559	11527.6181633
4	-0.6713104	-9.2097947	11528.1921374
5	-0.8629243	-9.0914112	11529.0031331
6	-1.0280969	-8.9386350	11530.0336416
7	-1.1612998	-8.7552045	11531.2632668
8	-1.2573726	-8.5455315	11532.6671424
9	-1.3115035	-8.3148415	11534.2148143
10	-1.3192454	-8.0693329	11535.8695882
11	-1.2766722	-7.8163855	11537.5862020
12	-1.1808063	-7.5647563	11539.3088693
13	-1.0304400	-7.3247220	11540.9675549
14	-0.8273466	-7.1080048	11542.4786257
15	-0.5776878	-6.9269793	11543.7446656
16	-0.2927353	-6.7870375	11544.6620184
17	0.0000000	-6.5735900	11545.1291698
18	0.0000000	6.5735900	11545.1291698

L= 79

K	U	V	P
1	0.0000000	-8.9502657	11527.7701552
2	-0.1876878	-8.9502657	11527.7701552
3	-0.3701853	-8.9216605	11528.0388417
4	-0.5406898	-8.8569000	11528.5077627
5	-0.6938329	-8.7617052	11529.1640657
6	-0.8245993	-8.6389612	11529.9929428
7	-0.9283364	-8.4919246	11530.9767919
8	-1.0007893	-8.3245070	11532.0936340
9	-1.0381656	-8.1413627	11533.3163674
10	-1.0372651	-7.9479834	11534.6119302
11	-0.9957333	-7.7507573	11535.9404619
12	-0.9124578	-7.5570107	11537.2544649
13	-0.7881525	-7.3749366	11538.4982462
14	-0.6260919	-7.2133489	11539.6093140
15	-0.4327693	-7.0809396	11540.5206131
16	-0.2175178	-6.9797220	11541.1679755
17	0.0000000	-6.7839476	11541.4925414
18	0.0000000	6.7839476	11541.4925414

L= 80

K	U	V	P
1	0.0000000	-8.6472858	11527.6949043
2	-0.1513538	-8.6472858	11527.6949043
3	-0.2985380	-8.6243298	11527.9218676
4	-0.4355802	-8.5728719	11528.3065038
5	-0.5579593	-8.4972399	11528.8384753
6	-0.6614826	-8.3997998	11529.5055817
7	-0.7423143	-8.2833374	11530.2923630
8	-0.7970464	-8.1512309	11531.1794477
9	-0.8228016	-8.0074913	11532.1436460
10	-0.8173983	-7.8567839	11533.1561799
11	-0.7795660	-7.7044217	11534.1838944
12	-0.7092485	-7.5563202	11535.1882326

13	-0.6079867	-7.4188184	11536.1259813
14	-0.4793141	-7.2984231	11536.9510400
15	-0.3290386	-7.2011718	11537.6177738
16	-0.1644883	-7.1271515	11538.0849252
17	0.0000000	-6.9430265	11538.3164520
18	0.0000000	6.9430265	11538.3164520

L= 81

K	U	V	P
1	0.0000000	-8.4024485	11527.2570896
2	-0.1223221	-8.4024485	11527.2570896
3	-0.2412428	-8.3840933	11527.4502459
4	-0.3515637	-8.3438778	11527.7673612
5	-0.4495333	-8.2847235	11528.2000537
6	-0.5316933	-8.2085167	11528.7379856
7	-0.5949209	-8.1175980	11529.3678391
8	-0.6365325	-8.0148043	11530.0733159
9	-0.6543918	-7.9034870	11530.8341133
10	-0.6470573	-7.7874832	11531.6265757
11	-0.6139451	-7.6710907	11532.4237878
12	-0.5555445	-7.5589596	11533.1949229
13	-0.4736257	-7.4559221	11533.9071964
14	-0.3714445	-7.3667352	11534.5269936
15	-0.2538301	-7.2955640	11535.0219915
16	-0.1264442	-7.2413605	11535.3654633
17	0.0000000	-7.0653289	11535.5341258
18	0.0000000	7.0653289	11535.5341258

L= 82

K	U	V	P
1	0.0000000	-8.2037932	11526.5919390
2	-0.0992684	-8.2037932	11526.5919390
3	-0.1956048	-8.1893918	11526.7582732
4	-0.2846461	-8.1587216	11527.0221169
5	-0.3633399	-8.1134018	11527.3762989
6	-0.4248472	-8.0549347	11527.8120647
7	-0.4786420	-7.9852545	11528.3180522
8	-0.5106167	-7.9066869	11528.8805711
9	-0.5231978	-7.8219426	11529.4830437
10	-0.5154544	-7.7340906	11530.1059122
11	-0.4872172	-7.6465201	11530.7277563
12	-0.4392086	-7.5628193	11531.3240821
13	-0.3731409	-7.4866398	11531.8703959
14	-0.2917897	-7.4214604	11532.3415520
15	-0.1989831	-7.3701662	11532.7148261
16	-0.0990155	-7.3310249	11532.9716849
17	0.0000000	-7.1611235	11533.0964821
18	0.0000000	7.1611235	11533.0964821

L= 83

K	U	V	P
1	0.0000000	-8.0419068	11525.8017118
2	-0.0609190	-8.0419068	11525.8017118
3	-0.1590481	-8.0312477	11525.9474638
4	-0.2310674	-8.0086581	11526.1694911
5	-0.2945059	-7.9748640	11526.4618332
6	-0.3470212	-7.9311244	11526.8172259
7	-0.3865597	-7.8790160	11527.2262628
8	-0.4114633	-7.8203885	11527.6777680
9	-0.4205690	-7.7573629	11528.1577716

10	-0.4132876	-7.6923189	11528.6508138
11	-0.3896894	-7.6278569	11529.1391062
12	-0.3505576	-7.5667040	11529.6049538
13	-0.2974279	-7.5116003	11530.0286124
14	-0.2325687	-7.4651256	11530.3917351
15	-0.1588761	-7.4293680	11530.6778374
16	-0.0794144	-7.4022768	11530.8735083
17	0.0000000	-7.2379837	11530.9669199
18	0.0000000	7.2379837	11530.9669199

L= 84

K	U	V	P
1	0.0000000	-7.9099767	11524.9647322
2	-0.0659719	-7.9099767	11524.9647322
3	-0.1290802	-7.9031390	11525.0948379
4	-0.1872597	-7.8872299	11525.2838964
5	-0.2384429	-7.8628866	11525.5279961
6	-0.2806648	-7.8312463	11525.8206176
7	-0.3122477	-7.7935560	11526.1543105
8	-0.3318897	-7.7512241	11526.5196684
9	-0.3387258	-7.7058472	11526.9056084
10	-0.3323935	-7.6592045	11527.2992785
11	-0.3130864	-7.6132244	11527.6871743
12	-0.2815654	-7.5699425	11528.0549536
13	-0.2391641	-7.5313973	11528.3879946
14	-0.1877025	-7.4995503	11528.6723274
15	-0.1292827	-7.4760854	11528.8959379
16	-0.0657674	-7.4591048	11529.0481160
17	0.0000000	-7.3016682	11529.1196416
18	0.0000000	7.3016682	11529.1196416

L= 85

K	U	V	P
1	0.0000000	-7.8037442	11524.1417224
2	-0.0531511	-7.8037442	11524.1417224
3	-0.1034842	-7.8006499	11524.2596279
4	-0.1500667	-7.7899908	11524.4233544
5	-0.1910588	-7.7732153	11524.6296423
6	-0.2248139	-7.7513375	11524.8733694
7	-0.2409803	-7.7252824	11525.1485753
8	-0.2655422	-7.6960626	11525.4477161
9	-0.2708679	-7.6648199	11525.7611993
10	-0.2657396	-7.6328270	11526.0793390
11	-0.2504011	-7.6014586	11526.3912390
12	-0.2255530	-7.5721890	11526.6855369
13	-0.1923356	-7.5465092	11526.9515226
14	-0.1522202	-7.5259484	11527.1781134
15	-0.1067337	-7.5120468	11527.3566480
16	-0.0566475	-7.5036231	11527.4788375
17	0.0000000	-7.3565535	11527.5357413
18	0.0000000	7.3565535	11527.5357413

L= 86

K	U	V	P
1	0.0000000	-7.7208541	11523.3792486
2	-0.0415035	-7.7208541	11523.3792486
3	-0.0807198	-7.7207811	11523.4874683
4	-0.1171924	-7.7140196	11523.6310783
5	-0.1492891	-7.7031311	11523.8079364
6	-0.1757006	-7.6888968	11524.0140381

7	-0.1953839	-7.6719458	11524.2440748
8	-0.2075765	-7.6529563	11524.4918997
9	-0.2118151	-7.6327047	11524.7501555
10	-0.2079886	-7.6120441	11525.0106464
11	-0.1963395	-7.5919137	11525.2649906
12	-0.1774879	-7.5733262	11525.5044336
13	-0.1523930	-7.5573492	11525.7204073
14	-0.1222729	-7.5451700	11525.9049955
15	-0.0883407	-7.5382672	11526.0512131
16	-0.0506767	-7.5365828	11526.1529135
17	0.0000000	-7.4056846	11526.2020874
18	0.0000000	7.4056846	11526.2020874

L= 87

K	U	V	P
1	0.0000000	-7.6594412	11522.7104659
2	-0.0307850	-7.6594412	11522.7104659
3	-0.0602323	-7.6611105	11522.8107693
4	-0.0876031	-7.6571893	11522.9391056
5	-0.1116710	-7.6507004	11523.0936120
6	-0.1314935	-7.6421598	11523.2704702
7	-0.1463080	-7.6319800	11523.4656754
8	-0.1555621	-7.6205850	11523.6742916
9	-0.1589324	-7.6084725	11523.8901722
10	-0.1563705	-7.5961639	11524.1069841
11	-0.1480981	-7.5842676	11524.3183012
12	-0.1346395	-7.5734272	11524.5169523
13	-0.1167815	-7.5643837	11524.6963250
14	-0.0955441	-7.5580220	11524.8509246
15	-0.0720314	-7.5556809	11524.9746973
16	-0.0462759	-7.5583673	11525.0632661
17	0.0000000	-7.4505761	11525.1102979
18	0.0000000	7.4505761	11525.1102979

L= 88

K	U	V	P
1	0.0000000	-7.6168504	11522.1573534
2	-0.0213895	-7.6168504	11522.1573534
3	-0.0422042	-7.6192346	11522.2522552
4	-0.0614645	-7.6173216	11522.3695087
5	-0.0784405	-7.6138604	11522.5069719
6	-0.0924778	-7.6092522	11522.6615715
7	-0.1030396	-7.6037644	11522.8304202
8	-0.1097363	-7.5976408	11523.0095136
9	-0.1123638	-7.5911587	11523.1939154
10	-0.1109050	-7.5846100	11523.3783173
11	-0.1055558	-7.5783450	11523.5577832
12	-0.0967357	-7.5727367	11523.7269114
13	-0.0850740	-7.5682627	11523.8806727
14	-0.0714183	-7.5655404	11524.0145969
15	-0.0568259	-7.5656470	11524.1244930
16	-0.0417713	-7.5701442	11524.2065425
17	0.0000000	-7.4911234	11524.2554369
18	0.0000000	7.4911234	11524.2554369

L= 89

K	U	V	P
1	0.0000000	-7.5899442	11521.7361162
2	-0.0135587	-7.5899442	11521.7361162
3	-0.0269989	-7.5924263	11521.8277584

K	U	V	P
4	-0.0395656	-7.5915825	11521.9362574
5	-0.0507305	-7.5899309	11522.0607753
6	-0.0600172	-7.5877935	11522.1995423
7	-0.0670674	-7.5852931	11522.3493921
8	-0.0716307	-7.5825397	11522.5072513
9	-0.0735927	-7.5796461	11522.6689289
10	-0.0729597	-7.5767538	11522.8304202
11	-0.0698966	-7.5740220	11522.9876275
12	-0.0647194	-7.5716362	11523.1366391
13	-0.0579239	-7.5698591	11523.2736367
14	-0.0502050	-7.5690673	11523.3954536
15	-0.0425443	-7.5700057	11523.4993892
16	-0.0358715	-7.5742467	11523.5820907
17	0.0000000	-7.5259706	11523.6375975
18	0.0000000	7.5259706	11523.6375975

L= 90

K	U	V	P
1	0.0000000	-7.5757933	11521.4594203
2	-0.0071873	-7.5757933	11521.4594203
3	-0.0151370	-7.5771961	11521.5468715
4	-0.0226231	-7.5766913	11521.6492238
5	-0.0292381	-7.5760490	11521.7654529
6	-0.0347284	-7.5753357	11521.8934166
7	-0.0389110	-7.5745538	11522.0309729
8	-0.0416669	-7.5737234	11522.1746760
9	-0.0429466	-7.5728637	11522.3212662
10	-0.0427739	-7.5720219	11522.4677632
11	-0.0412701	-7.5712410	11522.6108144
12	-0.0386569	-7.5705819	11522.7471600
13	-0.0352965	-7.5701428	11522.8742855
14	-0.0317401	-7.5700820	11522.9903283
15	-0.0288687	-7.5707712	11523.0951021
16	-0.0279569	-7.5733380	11523.1879550
17	0.0000000	-7.5531651	11523.2627402
18	0.0000000	7.5531651	11523.2627402

L= 91

K	U	V	P
1	0.0000000	-7.5700000	11521.3313634
2	-0.0030115	-7.5700000	11521.3313634
3	-0.0070247	-7.5700000	11521.4175108
4	-0.0103841	-7.5700000	11521.5178142
5	-0.0132068	-7.5700000	11521.6298523
6	-0.0154948	-7.5700000	11521.7520418
7	-0.0172148	-7.5700000	11521.8824270
8	-0.0183423	-7.5700000	11522.0177482
9	-0.0188646	-7.5700000	11522.1558633
10	-0.0188098	-7.5700000	11522.2935128
11	-0.0182404	-7.5700000	11522.4280889
12	-0.0172712	-7.5700000	11522.5574496
13	-0.0161034	-7.5700000	11522.6796391
14	-0.0150784	-7.5700000	11522.7943781
15	-0.0148804	-7.5700000	11522.9039016
16	-0.0172513	-7.5700000	11523.0147290
17	0.0000000	-7.5700000	11523.1482806
18	0.0000000	7.5700000	0.0000000

L= 92

K	U	V	P

1	0.0000000	-7.5700000	0.0000000
2	0.0000000	-7.5700000	11521.3313634
3	0.0000000	-7.5700000	11521.4175108
4	0.0000000	-7.5700000	11521.5178142
5	0.0000000	-7.5700000	11521.6298523
6	0.0000000	-7.5700000	11521.7520418
7	0.0000000	-7.5700000	11521.8824270
8	0.0000000	-7.5700000	11522.0177482
9	0.0000000	-7.5700000	11522.1558633
10	0.0000000	-7.5700000	11522.2935128
11	0.0000000	-7.5700000	11522.4280889
12	0.0000000	-7.5700000	11522.5574496
13	0.0000000	-7.5700000	11522.6796391
14	0.0000000	-7.5700000	11522.7943781
15	0.0000000	-7.5700000	11522.9039016
16	0.0000000	-7.5700000	11523.0147290
17	0.0000000	-7.5700000	11523.1482806
18	0.0000000	-10.0000000	0.0000000

APPENDIX IX

SAMPLE DIALOGUE FOR
COMPUTATIONAL INPUT PROGRAM

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KA, K?, LA, LI, UVEL, JVEL, KIN, KOUT

... , KA, YYA, ... R, DDZ

... , YA, ...

... , YA, ...

... , ... , ... RB, CRTZA, CRTZB, XMAX, YMAX

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APPENDIX X

SAMPLE DIALOGUE FOR ABMAC

MISSION
of
Rome Air Development Center

RADC is the principal AFSC organization charged with planning and executing the USAF exploratory and advanced development programs for electromagnetic intelligence techniques, reliability and compatibility techniques for electronic systems, electromagnetic transmission and reception, ground based surveillance, ground communications, information displays and information processing. This Center provides technical or management assistance in support of studies, analyses, development planning activities, acquisition, test, evaluation, modification, and operation of aerospace systems and related equipment.